The Hovering Ball Exhibit

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Statement of Disclaimer

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A Special Thank You…

We, the CP Planeteers, need to extend a deep-hearted thank you to the many individuals and organizations that helped to make this project a reality. Without their contributions, the Gear It Up museum exhibit would be just a design on paper, resting in electronic folders, data back-ups, and piles of yet-to-be-ever-graded reports in the vaults of Cal Poly ME faculty. Thank you, thank you for your support, encouragement, and patience.

First off, we must thank our sponsor, the **San Luis Obispo Children's Museum**. Thank you for entrusting us with your time, energy, and investment to create a machine that will be of benefit to your wonderful museum. This project has been an opportunity for us to prove ourselves as graduating Cal Poly Mechanical Engineers, and we are eternally grateful that we were so lucky to work on a local project to which we felt connected. Thank you **Michelle Jenkins, SLOCM Executive Director**, for your enthusiasm and encouragement! Thank you **Kathy Chen and Jennifer Jipson, Board Members**, for your great ideas and feedback!

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Table of Contents

List of Figures

List of Tables

Abstract

This document presents a senior project exhibit design for the San Luis Obispo Children's Museum. Included in this report is the progression of the ideation to the final version of "Gear It Up", its final design schematics, and the manufacturing processes. The final exhibit design showcases an application of human power and mechanical advantage through a machine that can be hand-cranked to power a blower. The air pushed by this blower is directed through a clear Plexiglas tube containing a ping pong ball, allowing users to visually experience the effect on the system of their pedaling. Gearing is used to create a favorable ratio between the hand-crank turning speed and the output speed at the fan shaft, allowing a user to comfortably crank at a speed that will cause the ball to perfectly hover. The dominant educational focus of the exhibit is the notion of the benefit gained by gearing, demonstrated by the difference in difficulty between the two differently-geared cranks.

Chapter 1: Introduction

The San Luis Obispo Children's Museum (SLOCM) is in need of new exhibits that are educational and engaging for children at the target age group of 8-12 years old. The exhibits must be economical in space and cost, durable to the abuse that children will subject them to, and most importantly, safe. The current exhibits are aging with some irreparable and the museum has expressed a need for something new and fresh which can capture the imagination of both children and adults alike. The Exhibits' Committee requested that the exhibits focus on energy related topics.

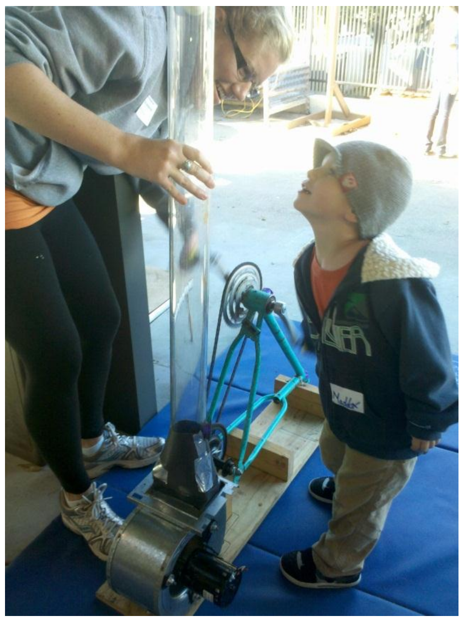


Figure 1 The Planeteers' Solidworks Master and Snacks Coordinator Michelle Swan shares the joy felt by a preschooler successfully testing out the Gear It Up prototype.

This document proposes a new design for a human powered exhibit that showcases how human energy is converted to fluid energy with the use of gears and a bicycle drivetrain, dubbed"Gear It Up". With this bike-inspired system, the CP Planeteers have designed a system that educates all ages interactively about energy conversion and mechanical advantage. The system provides real-time feedback aboutthe mechanical advantage of using gears and a hands-on visual representation of the conversion of human energy to fluid energy by lifting a ping pong ball with a jet stream.

Objectives

To aid the design of the overall system, goals of Gear It Up can be broken down into the following objective categories:

Safety

Since Gear It Up will be used primarily by children, safety is a key requirement. Although the design contains various potentially dangerous spinning parts, all potentially harmful components will be enclosed in Plexiglas casing, allowing zero pinch points or hazardous features. The finished exhibit will be safe for all users.

Accessibility

It is important that Gear It Up accommodates visitors to the museum of a large range of age, size, and abilities. It will be usable by wheel-chaired visitors without special accommodations, allowing them to be side-by-side with other children using the exhibit.

Space

In order to respect SLOCM's lack of floor space, the exhibit will be contained in a 2' by 2' square box with a footprint of about 4' by 4', and can be placed against a wall. In addition, Gear It Up will be portable. This will allow it to be dollied off the main floor if necessary and easily transported up the street to be put on display at San Luis Obispo's weekly Farmer's Market.

Durability

Most importantly, Gear It Up will be durable. The Planeteers have designed the exhibit to withstand aggressive all-day, every-day use. In the off chance that something does break on the exhibit, The Planeteers will be providing a detailed manual including clear descriptions of each component along with instructions to fix every potential problem. This manual will also include trouble-shooting and maintenance.

Specifications

During the design of the Gear It Up, all of the following requirements in Table 1 were considered using Quality Function Deployment (the completed model is attached in the appendix of this project proposal). The Quality Function Deployment (QFD) model allowed The Planeteers to further define the engineering problem and sort through each design specification, quantifying each one. The QFD model starts with the list of SLO Children's Museum's wants and needs (listed on the left hand side of the model). Each requirement is then assigned a number depending on its importance to the overall design (these numbers all add up to 100 and are located directly to the right of the requirements). This quantification allows us to decide how much time and money should be dedicated to each requirement.

Table 1: Engineering Parameters & Requirements

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Desired Fan RPM	1550 RPM	±500 RPM	L	A, T
2	Airstream Lift	50g	Min	L	A, T
3	Size	30 sq. ft	+10 sq.ft	L	I
4	Budget	$1000	Max	M	A
5	Arm Length	12-26 in	± 4 in	M	I
6	ADA sufficient	Yes	Min	M	I, T
7	Weight	100 lbs	± 10 lbs	L	A
8	Mobility	yes	--	M	I, T
9	Reliable	< 10 days / year	Max	H	A, T
10	Maintenance	5 minutes /week	Max	H	A, T
11	Captivation	5 minutes	Min	L	T
12	Education	3 Things Learned	Min	M	T, S

Next, various existing human powered exhibits were rated on how well they fit each of the requirements (this can be seen on the far right of the model). This rating is based on a 1-5 scale, 5 meaning that the competitor fully meets the requirement and 1meaning that the requirement is not met at all. The purpose of this section is to analyze and learn from the successes and failures of existing exhibits. With this knowledge of what works well and what does not, The Planeteers were able to optimize the design of the exhibit. After completing this benchmarking section, engineering specifications were developed. These specifications can be seen in Table 1.

The established specifications were mostly based on the sponsor's desires for this exhibit. For example, given the lack of space on the first floor, The Planeteers have limited the exhibit to only have a four square foot footprint. In addition, to cover many of the sponsor's display requirements, an engineering target was set for desired fan RPM, airstream lift, and captivation. With the first two requirements met, the user will be able to power the fan and levitate a ball for the display. This display will ideally captivate the user for at least 5 minutes. To cover the accessibility requirements, Gear It Up will accommodate arm lengths ranging from 18 to 26 inches and will be designed with ADA specifications in mind (implementation of hand crank). In respect to maintenance and reliability, The Planeteers set a target for less than 5 minutes a week of maintenance, and less than 10 days a year that Gear It Up will be out of order. Lastly, the sponsor's portability requirement will be satisfied with a mobility requirement and a maximum weight of 100 lbs. The size requirement will also play a part the portability along with the shape.

Once all of the specifications were set, they were analyzed by how well each met the given specifications. These were rated on a 9, 3, 1, or blank scale (9 having a high correlation and blank having no correlation at all) in the middle of the QFD model. Since it is important that the Gear It Up will satisfy the SLO Children's Museum's specifications, the engineering specifications set with the largest correlations to the sponsor specifications will receive the most attention. For Gear It Up, these include ADA sufficient, aesthetically pleasing, reliable, maintainable, captivating, and educational.

It was also helpful to set engineering targets and then relate the existing competition to them (can be seen in the lower section of the model). Just like the evaluation of the competition to the sponsor specifications will allow Gear It Up to be designed upon previous successes and failures, this also allows The Planeteers to gain insight into what is already available and what needs to be improved upon. These comparisons are very valuable in the design process of Gear It Up.

Team Management and Roles

Each team member will be responsible for a portion of the project and will have specific roles. These roles include main contact for sponsor, information gathering, documentation of project progression, manufacturing considerations, prototype fabrications, testing plans, etc. The roles also include which subsystem a particular team member oversees. Each team member is responsible for

asking for help and helping other team members as needed. This section specifies which role is fulfilled by which team member.

Michelle Swan:

- Manufacturing Considerations
- Feedback Subsystem
- Master SolidWorks Designer
- Snacks

Will Lennox:

- Primary Customer Contact
- Information Gathering
- Prototype Fabrication
- Team Motivator

Matt Bauzon:

- Documentation of Project Progress (Historian)
- Master Analyzer
- SolidWorks Designer Deputee
- Photographer

Kevin Wilkins:

- Materials Consultant
- Captain Falco/Planet
- Saving the World

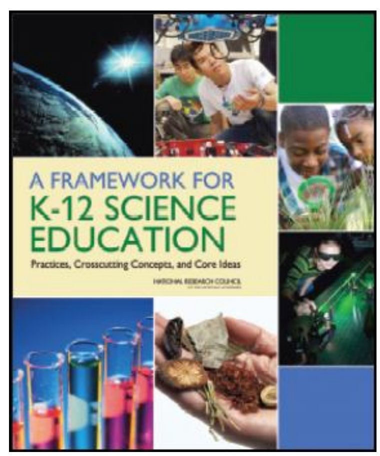
Chapter 2: Background

The San Luis Obispo Children's Museum is a unique center offering a fun educational experience for children and their parents. Exhibits in the museum engage visitors interactively, inviting them to touch and handle the exhibits and have a personal cause and effect relationship with them. The museum itself has a strong San Luis Obispo theme to it, with decorations and exhibits relating to the town and the surrounding area. The end product of the Blower-Bike will fit the common theme and expectations of existing museum exhibits by attention to the SLOCM's unique design criteria.

Codes & Standards:

Special consideration must be taken in the design of a product specifically for children. The end product created by The Planeteers will need to not only safely and reliably educate and entertain child visitors to the museum, but their parents as well.

Following is a look at several sets of guidelines that will be followed for this project:



A Framework for K-12 Science Standards:

Practices, Crosscutting Concepts, and Core Ideas

Report Brief – July 2011

Published by the National Academies, this report lays the framework for a curriculum of science education for K-12 students. Developed by a panel of 18 experts in the field of child education, and extensively peer-reviewed, it identifies what are believed to be important elements in three separate dimensions of science education: Scientific and Engineering Practices, Crosscutting Concepts That Have Common Application Across Fields, and Core Ideas in Four Disciplinary Areas.

This document can be used more as a reference to important learning objectives for children than as an actual set of guidelines for exhibit design.

SLOCM Museum Guidelines for Exhibit Production

This document was written to help guide exhibit creators in the development of an exhibit that meets the individual needs and expectations of the SLO Children's Museum. It emphasizes attention to the abilities of the end user, specifically to the target age group and associated floor where their exhibits are found. The SLO Children's Museum has asked for exhibits on the First Floor, designed for children between the ages of 5-10 years, the oldest expected age range at the museum.

Included in these guidelines are a list of design criteria, a reference to other relevant established standards (listed below), and a list of content for documentation requested by the museum.

SLO Children's Museum Exhibits Criteria Checklist

Exhibit:

Criteria	High	Med	Low
appealing, fun			
inquiry based, hands-on			
can do on repeat visits (different outcomes)			
multiple entry points (different ages, abilities) – universal design			
interactive, collaborative			
self-explanatory (vs. facilitated)			
experiences hard to repeat elsewhere			
fits within greater themes and other exhibits			
low maintenance (avoid computers, if possible)			
reasonable space and power requirements (portable?)			
durable			
safe			
sustainable (materials, energy consumption)			
learning objectives defined state standards: program extensions?			

Evaluation:

Guidelines for Exhibit Production

Figure 2 SLO Children's Museum Exhibits Criteria

Universal Design Guidelines

For NISE Network Exhibits

Nanoscale Informal Science Education (NISE) Network explains the concept of Universal Design: “the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation specialized design.” It emphasizes physical, cognitive, and social inclusion to promote access and engagement in an exhibit. Essentially, instead of creating specialized accommodations for the disabled, which separates them from the experience that other users have, the intent is to design an exhibit so that it is inclusive to users with all ranges of abilities.

Physical inclusion:

- Exhibits should be accessible to those with special mobility accommodations, such as wheelchairs and canes.
- Exhibits should provide a comfortable and welcoming ambience, including proper lighting and seating where applicable.
- Wherever possible, interface and artifacts of the exhibit should be tactile

Cognitive inclusion:

- Teaching through multi-sensory experience (activating several of the senses rather than just one)
- Audio descriptions, Braille translations, and bilingual captions on display.
- Imagery to support and replicate information.

Social inclusion:

- “Welcoming and inclusive”, not “separate but equal”
- If special accommodations must be made for the disabled, effort should be taken to ensure that they are not separated from other users.

Existing Solutions

Bicycles have been used to power many applications including electric generators, washing machines, blenders, and water pumps, to name a few. The bicycle-powered Bernoulli has been done before using a generator and an electric blower, but this solution was noisy and wasted energy on the conversion from pedal power to electricity. For The Planeteers' Gear It Up, the challenge will be to build a safe, reliable system that is appealing to children and adults, is intuitive and easy to use for users of all ability levels, and provides an interesting engaging interface to demonstrate the application of gears and power transfer.

Following are a few similar projects that have been built:

Kid Blower

http://pedalpowergenerator.com/

Figure 3 Kid Blower bicycle which power generator for electric leaf blower.

- Child-sized bicycle generator
- Rider's pedaling energy converted to electricity to run leaf-blower
- Two systems side-by-side for competition between children

The so-called Kid Blower uses several commercially available parts, including a bicycle, bike stand, and an electric leaf-blower. The generator is turned by means of a belt between the rear wheel of the bicycle and a pulley on the generator shaft. While the desired purpose of elevating the ping-pong ball is reached, the system has losses in efficiency due to the electricity conversion. Also, these electric leaf-blowers can be very noisy.

Bicibomba Movil

Jonathan Leary

Mechanical Engineering Master's Thesis – Sheffield University

http://www.mayapedal.org/LEARY_JL_2008_THESIS_1.pdf

Figure 4 BicibombaMovil in pumping mode.

- Mobile bicycle-powered water pump
- Designed for rural Guatemalans using recycled parts
- Capable of 4 liters/minute @ 25m of head.

The Bicibomba Movil is a good example of a mechanical solution to a problem using minimal resources. Nearly all the parts (minus the pump itself) were recycled from other bicycles or scrap metal sources. The Bicibomba uses direct friction drive from the rear wheel of the bicycle to the shaft of the centrifugal pump. The pump shaft is wrapped with an old bicycle tire and held on with wire, providing a textured, high-friction surface for the rear drive wheel to contact. The weight of the bike holds it on the pump, helping to avoid slipping. An adjustable frame holds the pump in place as well as lifting the rear tire off the ground, so that the machine is stationary.

Bicycle Blower

Exhibiteers, Inc.

Science World, Vancouver, British Colombia

Figure 5 Bicycle Blower, produced by Exhibiteers, Inc.

- Entire system contained to single platform
- Moving parts and pinch points contained
- Blatantly fun and enjoyable for users

Visitors pedal a bicycle that is connected to a blower, which keeps a ball suspended in an air stream. Users' peak energy output is measured by the height of the ball, and total work output can be measured by average ball height multiplied by time. A soccer ball is used in this exhibit, requiring a large centrifugal fan (seen in blue housing in figure). Another aspect to note is the opening, funnel-shaped housing tube for the ball to float in. This allows the ball to hover a bit, and demonstrate the Bernoulli Principle.

Chapter 3: Design Development

Objectives

It is essential that Gear It Up provide an interactive learning experience. A hands-on user interface not only supports our “Learn by Doing” learning objective, but also attracts museum members to the exhibit and delivers an overall more enjoyable and gratifying experience. In order to promote this objective, Gear It Up will include two points of access for visitors to turn the cranks of the exhibit. Both cranks will be hand-pedaled so as to further increase accessibility, and at two different heights. The lower crank will be at the ADA recommended 30” height for hand-turned equipment. The other will be at 42” to be accessible for small children and adults alike. The hand crank will turn an intermediate gear cluster, which will in turn spin a small ceiling fan by means of a speed step-up. The fan will create a jet stream blowing through a clear plastic tube causing a ping pong ball to hover. Should the user pedal fast enough to cause the ball to lift out of the tube, it will hover in open air on the jet stream above a funnel contraption, demonstrating the Bernoulli Effect. This will be an added bonus of the display.

By conveying to the user that the power they generate is directly related to how hard they pedal, it will stimulate the connection between their personal energy and the energy transferred to the fluid and ball. This will motivate the user to pedal fast and hard to lift the ball all of the way out of the tube. When there is another user on the other crank, it should be noticed that one crank is much easier to make the ball lift with than the other, due to differences in gearing. Hopefully the user will be captivated for a substantial period of time, making the exhibit very popular. In addition to the main display, the components of Gear It Up will all be visible behind a Plexiglas display, allowing viewers to see the mechanical workings of the exhibit and follow the transfer of energy from the pedal to the fan.

In the past, the SLOCM has had issues with senior project exhibits that stopped functioning prematurely. From these experiences, it has been requested that The Planeteers’ design specifically not contain any computer control. That being said, The Planeteers will gladly avoid all computer controls.

Ideation Progression

The progression that led to the current concept of “Gear-it-Up” included many intermediate steps. In October an informal project proposal was presented to the SLOCM Exhibits Committee, narrowing the project scope to two of four that were proposed (Human Powered Radio, Ferro Fluids, Simple Machines, Laser Puzzler). Of the two projects selected by the Committee, Human Powered Radio and Ferro Fluids, the former was selected to be pursued by Matt Bauzon, Will Lennox, and Michelle Swan, Gear It Up designers and co-authors of this report. Two teams were split out of the original seven-person group, and The Planeteers team was born. At this point The Planeteers set to focus on designing a system that included a bicycle which would power an electric generator, and in turn a radio.

Human-Powered Radio Concept

The original concept presented to the SLOCM Exhibits Committee, originally sparking the idea of a pedal-powered exhibit into the heads of the Committee members.

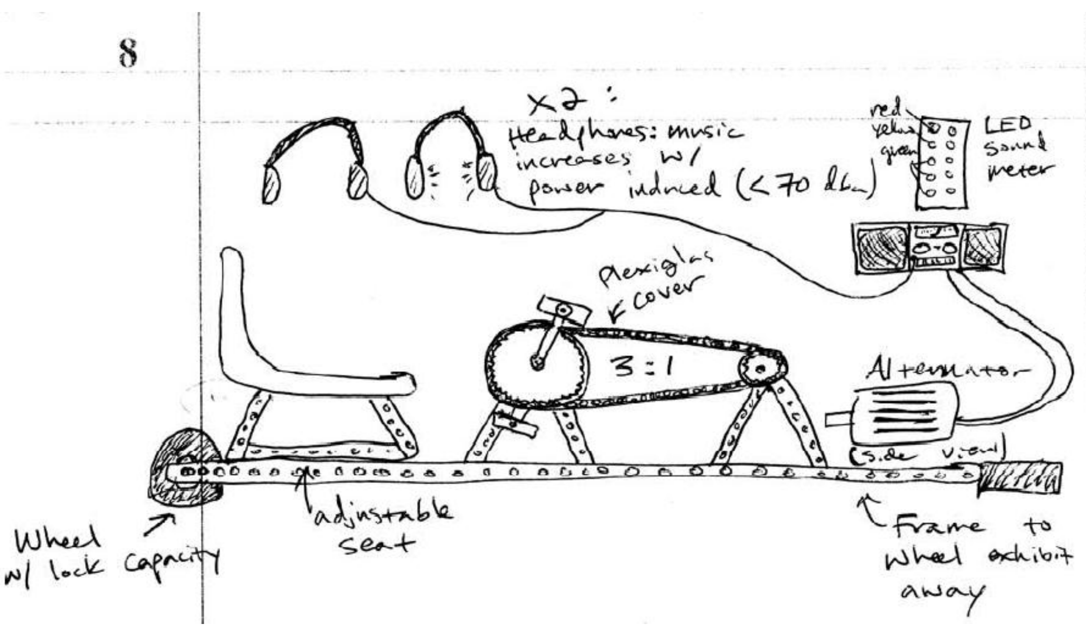


Figure 6 Original “Human-Powered Radio” concept proposed.

After further design development, The Planeteers decided to change form of the exhibit to an actual bicycle, rather than a recumbent. This decision was made to avoid complexity of the design, and to reduce the possibility of pinch points in the adjustable seating. Eventually, the display was changed from

a radio to a leaf blower, in order to satisfy the customer's expressed desire for a Bernoulli Blower type of display. This was the beginning of many changes along the way to arrive at Gear It Up.

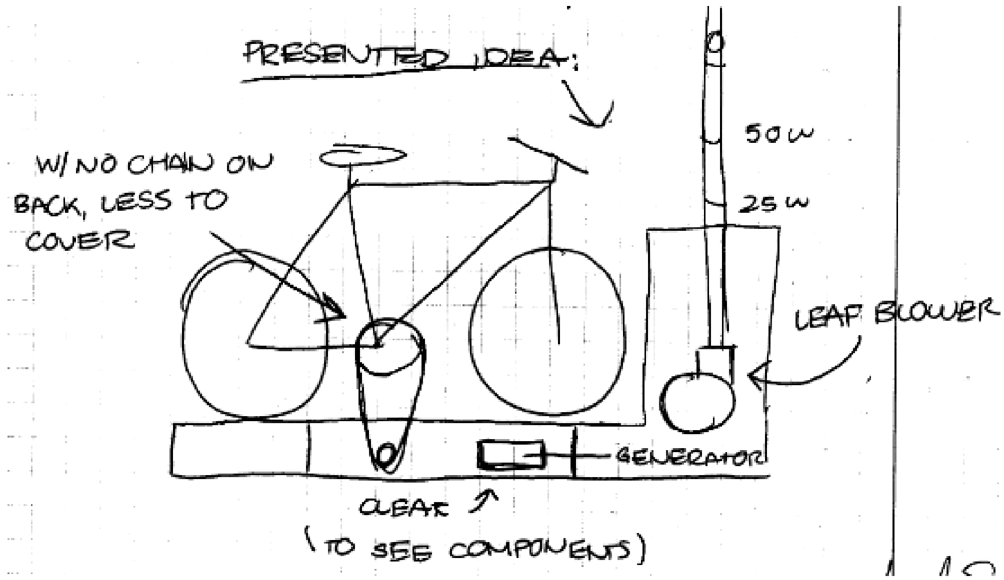


Figure 7 Electric-powered leaf blower concept, presented at Exhibits Committee meeting.

The Bike-Blower Concept

At the Exhibits Committee meeting, several issues with the electric-powered leaf-blower arose, such as noise and complexity. It was pointed out that it would be redundant to use a bicycle to run a motor which would turn a fan, when the bicycle could turn the fan directly. To avoid these issues, an intermediate design concept was reached, the Bike-Blower shown below in Figure 8. This would be a BMX bicycle which users could sit on to pedal, mounted to turn a fan directly without electricity.

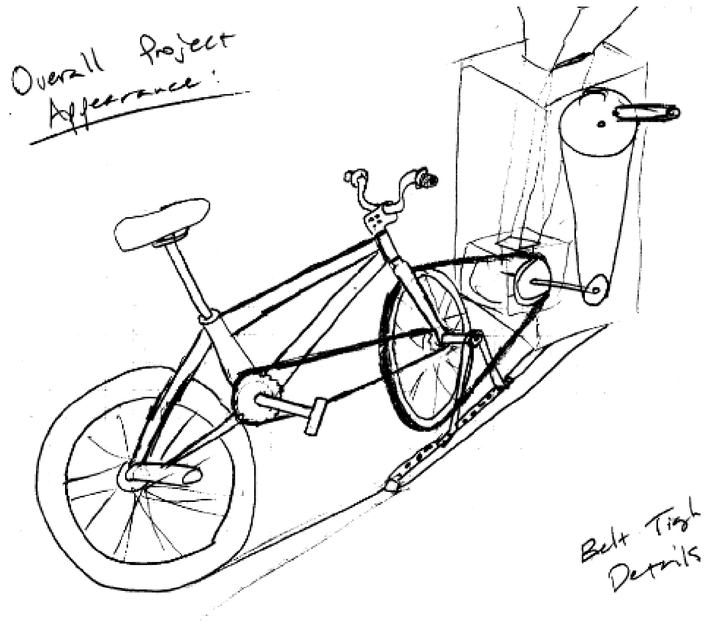


Figure 8 Initial concept sketch of "Bike-Blower". Note the front-wheel drive of the bicyle, and the belt-pulley power transfer system used.

Ideas were put to paper, and hand-drawn schematics were modeled in Solidworks. Figure 9 below shows a rendering of the Solidworks model. It was also decided along the way that a separate, hand-turned crank would be included as well in order to accommodate visitors to the SLOCM who may be physically handicapped, and could not pedal with their legs.

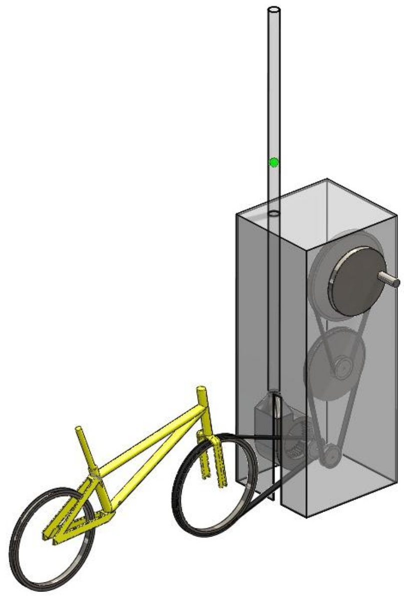


Figure 9 Isometric View of "Bike-Blower" Assembly

The cranking motion would be transferred by belts and pulleys, and both cranks would turn the same fan simultaneously, promoting teamwork and inclusion around the exhibit. One concern around this design would be the added complexity of converting a bicycle to turn the front wheel. This was desirable to keep all of the fast-spinning parts contained tight into the Plexiglas-covered frame of the housing. Despite the popularity of the Bike-Blower to The Planeteers, the Exhibits Committee would make an executive decision to scrap the bicycle altogether after the Conceptual Design Report was submitted, promoting the design of the Bike-Blower Concept.

The Prototype Process

Before the final design for Gear It Up could be completed, it was decided that a prototype demonstrating the concept should be built. Hand drawn plans for the prototype were made, a bill of materials compiled, and prototype construction began by mid-January. The goal of the prototype was to create a proof of concept model that physically showed how our system would work, and to test how children would interact with it.

The drive-train component of the prototype consisted of the “power triangle” of a bicycle: the section of the frame containing the seat-tube, chain-stays, and seat-stays. This was easily scavenged in the bicycle graveyard at the ME Hangar. A crank-set was left on the frame and it was mounted on a 8”x36” piece of plywood, seat stays clamped down to the wood and center-hub held aloft. A bicycle rear hub and gear cluster were mounted in the dropouts of the bicycle frame, and a chain was ran from the crank-set to the smallest gear on the cluster, providing a 1:4 speed increase ratio.

On the other side of the plywood the blower fan was mounted by driving two screws through its housing down into the wood. A right-angle bracket was made from 2x4 wood scrap to brace the fan against the pull of the chain, and again a screw was driven through the fan housing into the bracket to keep it in place. In order to turn the shaft of the fan, a coupler had to be manufactured. The goal was to mount a small bicycle cog onto the shaft of the fan, so that the fan could be turned by cranking the pedals on the bike frame. There would be another chain from the largest gear on the cluster to the cog on the fan shaft, providing a 1:3.5 speed increase. Combined, this two-stage speed step up achieved a 1:14 speed ratio, and at a steady 100 rpm by the user, a satisfactory 1400 rpm at the fan could be obtained. This rotational speed was desirable as it was near the 1550 rpm that the fan was designed to operate at.

The manufacturing plan for the coupler was to drill a 3/8” hole into the end of a metal rod, and place a set screw that could be tightened into this hole. This could be slid over the D-shaped shaft of the fan and the set screw would tighten it on. On the other side of the rod the cog would be attached. On the first attempt to manufacture this coupler, a steel cog was welded onto the end of the rod, but the axis weren’t aligned sufficiently and the cog would wobble when the rod was turned.

This wobble was sufficient to cause excessive vibrations in the fan, and to throw the chain.

It was decided to manufacture a new coupler from scratch, so 1.5” aluminum rod stock was purchased, along with a new 14-tooth, 3/32” thick SOMA Track Kog. In one Saturday at the Hangar, mostly spent on the lathe, a prototype of the coupler was built, followed by a fully-functioning final version. The aluminum was cut to length with a band-saw. The center hole was drilled with the lathe, the rod was turned down to decrease its mass, and it was threaded on one end to accommodate the cog. The final version was clean and precise, and fixed all previously had issues with the fan wobble and chain throw.

Figure 10 The final version of the coupler being lathed in the ME Hangar.

With the fan properly being turned by the cranking of the pedals, a jet stream of air was created that was sufficient to float a ping-pong ball in open air. A funnel was crafted from paper board and duct tape to channel air from the fan into the tube, in which the ping-pong ball would float. For out testing one team member would need to hold the tube upright, as it was not necessary to build a proper mount for the tube just for the prototype. Figure 12 shows the prototype.

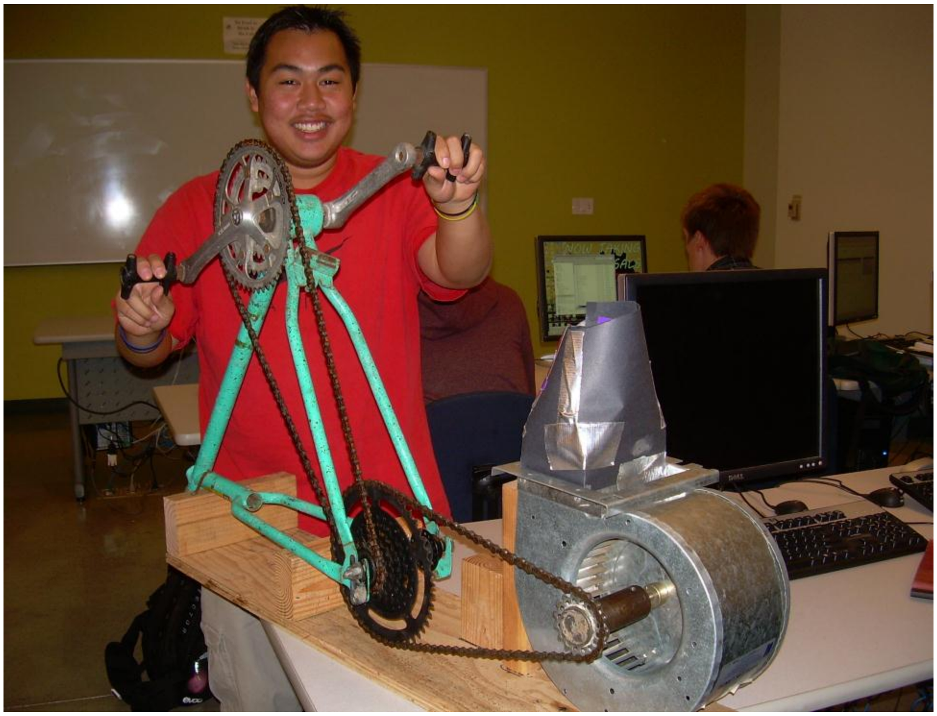


Figure 11 Gear It Up concept prototype. The coupler shown here is of the 1st attempt. It would later be replaced with the aluminum, threaded version.

Prototype Testing

Once it was built and functional, the team hoped to test the prototype with children of the target age range (age 8-12), and to study how they would interact with it. After trying it out with other ME students during a senior project lab session, it was verified that the machine worked soundly and was safe enough to have children try out. With the comforting knowledge that the for college students the prototype was easy to operate and entertaining The Planeteers took it to the preschool on campus to try it out with the 4-6 year olds. While the design age group for the project was 8-12 year-olds, the exhibit should ideally be attractive to any younger visitors as well.

Figure 12 Many of the children at the Preschool Lab were fascinated by the machine.

Assuring her that the prototype was safe and ready for testing, The Planeteers set an appointment with Jennifer Jipson, Director of the Preschool Lab on campus, and took the prototype in on a Friday morning. This visit would turn out to be invaluable for The Planeteers. Watching the preschoolers use the machine gave the team key insights in how the system should be oriented, the amount of effort needed for sufficient flow in the tube, and how fun and easy to use the interface was. Many of the kids were intrigued by the machine, and couldn't wait to try it out. At the same time, some were a little intimidated. The preschoolers were at an age where some were fully capable of using the machine on their own, while others would soon grow into it. This testing session shed light on the vast range of abilities of the future machine users. Those who could not use the machine easily could be

assisted by an adult cranking the other pedal. Figure 14 shows the size of one of the preschool kids compared with the prototype.

Figure 13 Testing with Preschoolers

The prototype stilled needed to be tested with the target age range. Fortunately, as the team was leaving the Preschool Lab, the Learn by Doing Lab across the hall was about to receive 4^{th} and 5^{th} graders a science lesson. This so happened to be the perfect age needed, so The Planeteers obtained permission from the head of the lab, and set up on a table to test the prototype with the children. This yielded very valuable insight on how children age 8-12 would react to the design. They were much more knowledgeable about the concept of gear ratios and the transfer of energy from their hands to the fan than was originally expected. They loved blowing the ball to the top or to try to keep the ball in the middle of the tube.

Prototype Lessons Learned

Building the prototype enabled The Planeteers to make many valuable insights into the best design for Gear It Up, the most important of which being that children of this age were attracted to learning about gear ratios. In fact, they seemed to gravitate more towards that aspect of the prototype than the energy conversion. With these observations, The Planeteers decided to focus less on the energy conversion learning objective, and concentrate on the feature mechanical advantage. After a visit to the SLO Children's Museum, better ideas of the size requirements and space usage by other exhibits were obtain for the final design. After testing, the following decisions were made about the final design of Gear It Up.

Two-handed or single-handed?

It was decided that Gear It Up would use a traditional **two-handed crank** as it would be best for the kids who visit the museum. From testing out the prototype, the feedback from the users was that it is easier to pedal with two hands than one. There is a chance that real small children won't be able to easily coordinate using both hands, but if they are that young then they will be accompanied by parents, who will benefit from being able to use the second pedal to assist their child in pedaling the exhibit.

Different Gear-Ratios or Identical Competitors?

Before testing of the prototype, it was unknown to The Planeteers if the concept of gearing was too complicated for children of the target age. The two drive systems were intended to be identical originally, and users would compete by cranking faster than one another. But with the goal of demonstrating gearing in mind, it was decided that there would be more of a learning experience available if the **two cranks were geared differently**. This way, questions could be asked such as, "Which

is easier to make the ball rise?", "Why is that?", and "Where else in the museum can you find gears at work?"

Having distinctly different gear ratios would allow the children to identify/learn why the fan turns so much faster than they are cranking and how that mechanical advantage transfers power and energy. With two identical crank configurations, the children would be prompted to physically pedal faster, but there would be less of an "aha" learning experience.

Two-story tall tube?

In the Exhibits Committee's feedback to the Concept Design Report, a two-story tube for the ball to rise within was requested. While it would be awesome to see, it would have limitations. After visiting the museum, to test the prototype on the museum floor and scout exhibit locations, The Planeteers noted that there would be only two locations in the whole museum where the two story tube would be feasible, and both would require moving other exhibits. Once the two story tube was installed with mounting brackets on the wall, it would be semi-permanent. It could be made removable, but the exhibit could not be moved to work in another location. In response to this limitation, The Planeteers came up with an alternative of a **6-ft tall tube with a funneled opening**, over which the ball would hover in the air. This way, if the user was able to lift the ball out of the tube by pedaling fast enough, the ball would still hover on a jet stream of air, but return into the tube when the fan is not being turned.

Chapter 4: Description of Final Design

Final Design: Gear It Up

At the end of Fall quarter The Planeteers submitted a Conceptual Design Report to the Exhibits Committee documenting the design process leading to that point, demonstrating the team's understanding of project objectives and criteria, and showcasing preliminary drawings and modeling. In response to the Conceptual Design Report, the Committee requested that The Planeteers change the design of the exhibit to include **two hand-cranks,** and scrap the bicycle altogether. The thought behind the request was that it would increase the accessibility and simplicity of the project, while also limiting its space requirements.

With the decision to switch to the two hand-cranks, the question arose regarding how to combine the two cranks. Initially it was considered that the two cranks would power the same blower, each connected to the fan shaft by a free-wheel so that they may turn separately while simultaneously contributing power. This concept was complicated, and seemed limited in its attractiveness to children. If Gear It Up were not to promote teamwork, then it would have to promote competition. It was decided that each crank would power a separate blower, and that the height to which the ping pong balls were lifted could become a point of competition between simultaneous users.

With the goal of teaching mechanical advantage to the children with gearing in mind, the final design includes two differently geared drive-trains. Everything about the two separate cranks will be identical, except for the chain-ring at the crank. This will simplify the difference in gearing, allowing users to easily see the variation between the two. The chain-ring at the lower hand-crank will be significantly larger, creating a higher speed ratio, and facilitating lifting the ball. With prompts in the exhibit display, users will be challenged to figure out the gear ratio, and the concept will be related to

other applications of gears in their everyday lives and around the museum. The ratio of the bottom crank is 7.4 to 1 and the ratio of the second crank is 6.3 to 1.

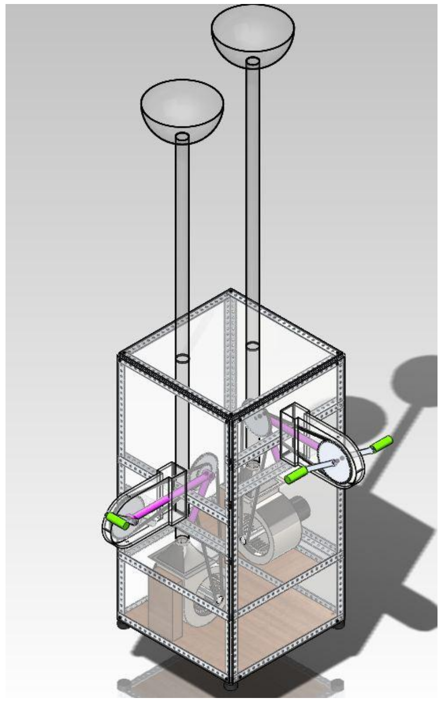


Figure 14 Solidworks rendering of the final design.

Shown here in Figure 14, the fans are mounted on MDF particle board within a galvanized steel angle frame. The frame is bolted together with 3/8”- 16 thread bolts, and will provide the structure of the project for mounting other components. The frame rests on rubber feet so as to protect the museum floor. As can be seen in Figure 14, Gear It Up is nearly entirely enclosed in Plexiglas, protecting users from potentially hazardous moving parts such as the chain, the gear clusters, and the fans. The clear Plexiglas will prevent visitors from reaching into the machine and causing themselves harm, while allowing the components to be easily viewed.

See Appendix F for detailed drawings for Gear It Up.

Final Product

The final product differed slightly from the final design. The figure below shows the finished product.

Figure 15 Final Product and Team

Instead of the two-handed system that was originally planned, we decided on a one-handed system. The shift from the design was for ease of construction and maintenance. The one-handed system was, according to various users, easier to use than a two-handed system. This is because the users can now brace themselves on the with the frame for more control and the speed at which users can crank the machine is increased. For the top of the tubes, we decided on a globe rather than a bowl. The globes are drilled full of holes so that air can pass through them with minimal resistance to the flow. The bowls were scrapped because they would need to be very large in order to catch the balls. The frame is mounted on a wood base which ensures that the machine sits in a level stance while operating.

The biggest change from the final design was that one of the fans was flipped in the opposite direction. In the Solidworks model, the two fans face opposite directions, which meant one of the cranks had to be pedaled clockwise instead if the more favorable counter-clockwise. Counter-clockwise is more

desirable because it felt more natural to the user to pedal in that direction. Flipping the fan, forced the bike frame paired with it to move to the left. This opened up the door of a one-handed system because there was much more room to accommodate it. The team also added multiple balls and ribbon inside the tube. The ribbon gave the user a sense of what was happening inside the tubes and the extra balls provided more things to entice the user with more visual aspects.

Analysis Results

Initial analysis of the components most likely to fail, mainly the bike chain, yielded a very high factor of safety. This is reasonable because bike chains are designed to withstand the punishment of cycling. A human can only put out about a quarter horsepower with their legs. Since the exhibit relies solely on arm power, we deemed further analysis of the chains unnecessary. Another failure point the team analyzed was the bike frames themselves. The results told us basically the same think as the chain. The safety factor was very high because the frames where meant for cycling. The loads that they were experiencing significantly smaller for our application. None one of the other components would experience as much load as the bike frame and the chain during operation. Therefore any further analysis on the system would be unnecessary.

Cost Breakdown

The prototype cost approximately $35.00 to manufacture. The team only purchased 2 feet of 1.5” aluminum round stock and a 14 tooth cog, the rest of the materials were procured either from machine shop scrap piles or donated by Mechanical Engineer staff and faculty. In fact, many of the components found on the final product were not paid for by the team. The components from the prototype where recycled in the final design. The final cost of the project came out to be $843.73, much lower than the $1,000 ceiling we were given. From recycle parts and using second-hand components,

the team saved a total of $577.00. The total cost and vendor list are detailed in our Bill of Materials found in Appendix C.

Material/Component Selection

The final product is composed primarily of steel. The bike frames are Chromoly steel and frame is mild steel. Originally, the exhibit was to be built primarily with aluminum to reduce weight. Unfortunately, angle aluminum was not available in the price range we wanted, so angle steel was chosen. In the case of the bikes, the frames that fit our application were made from steel. All the gear clusters and sprockets were found as handouts from bike shops and from the bike graveyard outside the Hanger. The chains used in the drive strain are standard bike chain.

The fans are Penn-Berry air conditioning fans. One of the fans was given to the team by Jesse Maddren of the Mechanical Engineering Department. The fans came as part of an HVAC unit which we had to pry off. To stay consist, we purchase the same fan from a Penn-Berry distributor. The output of the fan could easily be adjusted using proper gearing. The coupler which linked the chain with the fan shaft was custom made with aluminum stock and a bike cog.

Acrylic was used as the cover of frame and chains. It was chosen because it was cheaper than poly-carbonate and, more flexible and resilient than glass The tubes and globes were also acrylic. Because of this, we had to be careful. Acrylic is susceptible to vibration and is easily scratched. The combination of the transparent acrylic and the bright pain used on the internal components provided an aesthetically pleasing view.

Safety Considerations

Although we took specific directions to make the final product the as safe as possible and kid friendly, we found that there were still areas which need to be considered. If the exhibit is placed on a non-level surface or if someone is leaning on the machine, there is a danger of it tipping over. Although the risk is minimal, there is a small chance that I could happen. Unlike the final design, the rotating crank arm is not covered like we planned. This introduces a pinch point shown below.

Figure 16 Pinch Point at Crank Arm

The spinning crank arm also is a danger if the user lets go. A child or person can get struck by the spinning crank arm. This can be avoided by creating a zone that can only be entered by the user. Observers would stand outside the zone while the exhibit is in operation. Another concern is sudden jerks and stops while cranking the machine. Wild, aggressive movement on the crank can cause damage to the machine and initiate any number of problems such as the chain derailing or the Plexiglas cracking. Smooth, continuous motion is recommended to avoid downtime.

Maintenance and Repair Considerations

For optimum performance, the chain should be lubricated every month using bike chain lube which can be purchased from any bike shop or athletic store. The crank handles and any rotating parts should be greased intermittently. The Plexiglas covers should be cleaned using cleaners such as Brillianize or the Novus set every other week. Since the acrylic is susceptible to scratches, cleaning and polishing is a very important. The chain must be tightened properly or it will be more likely to derail. The Planeeters designed a system of tightening the second stage of the chain by lifting the entire bike crank assembly up. About two people are needed to complete this operation. In the event of the chain is stretched to the point of breaking, replace the chain with standard bike chain.

Proper operation, maintenance of various parts, repair of broken components, and a list of the replacement parts is included in a separate user's manual and maintenance guide. This guide will be included with the final report and exhibit when it is delivered to the museum.

Chapter 5: Product Realization

Manufacturing Process

Figure 17 Will and Matt playing with prototype in the beginning of Spring Quarter.

The Planeteer's started off Spring quarter with the prototype seen above in Figure 15, a rendered Solidworks design as seen in Figure 14, and various required parts and materials ordered. With just 10 weeks left to build, test, and deliver Gear It Up, the CP Planeteers started Spring quarter off with a tight, detailed building schedule, aiming to complete building in the first 5 weeks. Several days a week the Planeteers could be found at the ME Hangar on campus manufacturing and assembling the Gear It Up exhibit.

Following is a description of the processes undertaken to build the machine:

Figure 18. Angle Iron Frame.

The manufacturing process started with the cutting and assembling of the angle iron frame. The angle iron came in 8-feet long pieces which were cut down into four 4-feet long pieces and sixteen 2-feet long pieces using a compound miter. We then assembled the pieces into the frame shown in Figure 16. The pieces were fastened with ¼”-20 x ¾” long hex bolts with nuts and aluminum washers and tightened with a 7/16” socket wrench.

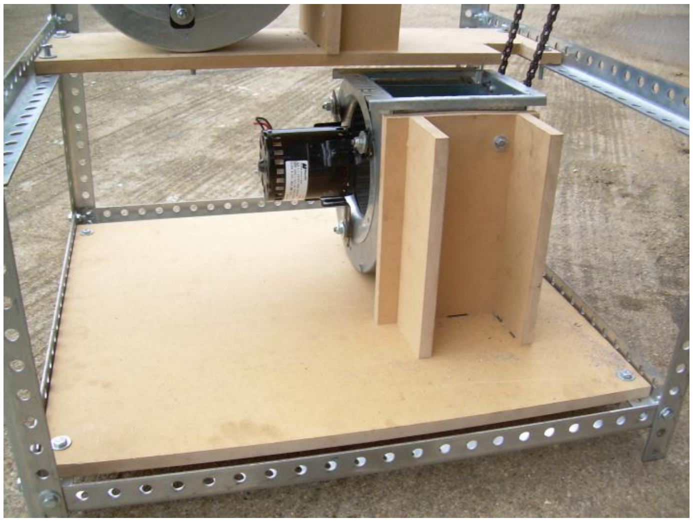


Figure 19. MDF Fan Base and Supports.

The next step was to size and cut the MDF for the fan bases and supports as shown above in Figure 17. For the two bases, the angle iron frame's dimensions and fan casing's width and length were taken into consideration when sizing. The pieces were then cut using a table saw and fastened to the frame using longer hex bolts (¼"-20 x 1 ½" long) with aluminum washers. The MDF supports were sized also using the width of the fan casing along with its height and cut using a table saw. These pieces were then attached to each other and the base using wood screws in the orientation that can be seen below in the finished "base" of the Gear it Up exhibit shown in Figure 17.

The fan casings were then mounted to the supports and base using the same longer hex bolts used to attach the MDF base to the angle iron frame. In order fit the bolts through the fan's sheet metal casing and the pieces of MDF, the Planeteers drilled ¼" holes in each using a cordless drill and increasing drill bit sizes. Once the fan casings were mounted, the fans were then reattached to their casings.

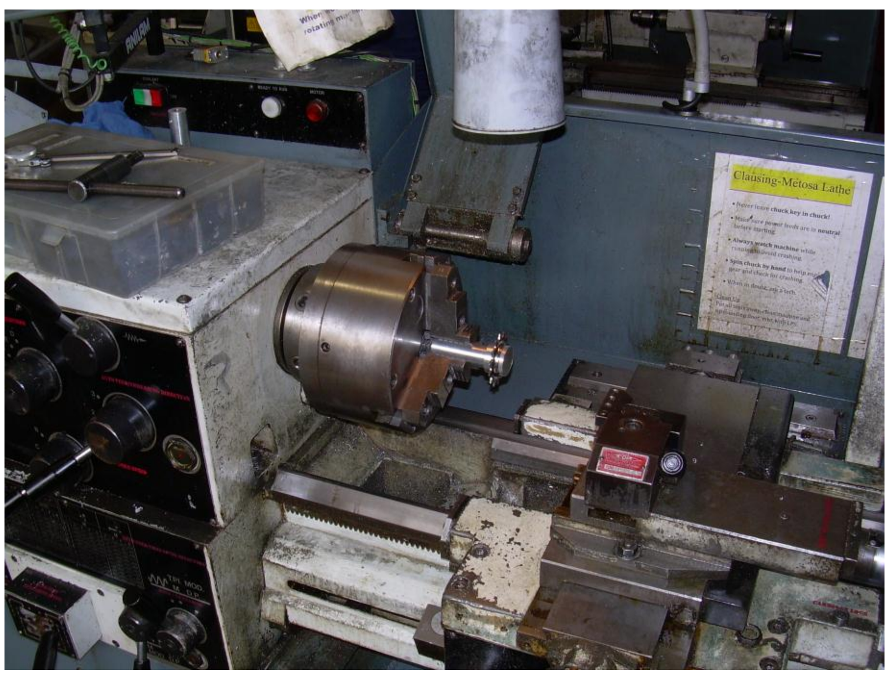


Figure 20. Planeteer Will Lennox manufacturing one of two couplers on the lathe.

The couplers that attach a bicycle cog to fan shaft were manufactured from scratch. A 1.5” aluminum rod stock was purchased, along with a two new 14-tooth, 3/32” thick SOMA Track Kogs. In one Saturday at the Hangar, mostly spent on the lathe, two couplers were built; the aluminum was first cut to length with a band-saw, then a center hole was drilled with the lathe, the rod was turned down to decrease its mass, and it was threaded on one end to accommodate the cog. This part can be seen in the lathe in Figure 18.

Figure 21. The lower hand crank's bicycle frame mounted on the frame.

Each hand crank was built out of bike parts either found in Cal Poly’s “bike graveyard” or donated to us by Joel Westwood. The first step in manufacturing was to cut the bike frames down to about two thirds of the back triangle into the “L” shape as seen in Figure 19. All of the cutting was down with an angle grinder and then filed down for precision with a grinding wheel. These “L”s were then mounted to the angle iron by lining up the gear clusters with the cog on the corresponding mounted fan and marking where angle iron holes lined up with the bike tubing. We then used an overhead drill press to drill holes in the tubes and then attached them to the angle iron with ¼”-20 x 1 ½” hex bolts.

The only modifications made on the bicycle's crank sets were the removal of one crank arm on each set, the manufacturing of new ergonomic hand pedals, and for the lower hand crank (larger gear ratio) a chain ring with a greater diameter and number of teeth was welded onto the spider mount of the crank. The description of the process used to make the new pedals is listed below.

An online search for hand pedals that could be purchased for Gear It Up returned only extremely expensive (~$250) results. Thus it was decided that the hand pedals would be manufactured by the Planeteers. Using 1-1/8" aluminum cylinder stock, pedal housings that were compatible with standard bicycle pedal spindles were machined on the lathe in the ME Hangar.

First, 5-1/2" lengths of the aluminum stock were cut using the horizontal bandsaw, and ½" thru-holes were center-drilled in each with the lathe. Next, each side was counter-bored to 7/8" to accommodate a steel ball bearing, and the spindle. The design of the spindle allowed that a nut could tighten down on the end of the spindle, effective tightening the bearings on each end into the pedal housing and holding everything snugly in place. A standard bicycle handle bar grip was fitted over each pedal, and a professional look was obtained.

Figure 22. Installation of Sheet metal transitions.

In order to maximize the air flow potential from the fan to the plastic tubes, we outsourced to Wighton's, a local HVAC company, to manufacture sheet metal transitions. The parts gently transitioned a 3.75" x 5.5" rectangular opening to a 3" circular tube opening. To make sure an airtight seal was achieved, the Bituthene (a self-adhesive waterproof membrane was placed in between the fan casing's hole opening and the transition. The transition was fastened down tightly using self-tapping sheet metal screws. The transitional parts can be seen attached above in Figure 20.

Figure 23. Painting the Gear it Up exhibit in the Planeteers' front yard.

After completing all of the mechanical aspects of the Gear it Up exhibit, the Planeteers dissembled all of the components to paint it the colors chosen by the Children's Museum. The frame was assigned a bright blue while the hand cranks with their corresponding fan and MDF base were painted with orange or bright green.

Figure 24. Planeteer member Michelle Swan using a jigsaw to cut slots for extruded bike frame

The last part of the manufacturing process was making the exhibit entirely child-safe. This required extensive Plexiglas covers. The first step to making these involved cutting three 23”x47” panels for the sides of the exhibit. In order to accommodate the extruding bike frames, patterns of necessary slots were first drawn up on cardboard and then transferred onto the corresponding Plexiglas panel. These patterns along with all sharp corners and necessary slots for bolt heads were then cut out using a jigsaw. This process can be seen above in Figure 22.

Figure 25. Plexiglas covers for hand cranks.

Lastly, the chain rings and chain outside of the main frame needed to be contained yet visible to the public. Our solution to this predicament can be seen above in Figure 23. The process to make these covers included initially cutting the rectangular sides for the covers then marking and cutting the curved end using a jigsaw. Once the overall shape was achieved, the Planeteers drilled an appropriately sized hole in one of each of the cover-sets to accommodate the crank arm. It was also necessary to cut a slot in holed Plexiglas side in order to slip it over the bike frame. This was done on the table saw can be seen below in Figure 24. The slot was later covered by gluing on a small strip of Plexiglas.

The two Plexiglas sides were then attached together using a strip of sized and bent aluminum sheet metal that can also be seen in Figure 23. The tools used to manufacture this strip of sheet metal include the sheet metal cutter, a punch, and sheet metal bender. All of the materials were fastened together in place with 2" posts with cut-to-size spaces in between to avoid the collapse of the cover. The cover was supported by drilling two holes in the bike frame approximately 6 inches apart using a cordless drill and then placing two 2" posts through the bike frames and through each side of the Plexiglas.

Figure 26. Planeteers Michelle and Matt cutting a slot in the hand crank cover.

Lastly, the Plexiglas tubes were cut to size so that the overall height of the exhibit would not surpass seven feet tall and holes were made in the Plexiglas globes we ordered. The process used for making these holes required a propane burner, a nail head, and a pair of vice grips. Plexiglas is a very brittle material and to avoid the cracking or fracturing of the globes, it was determined that the best method of "drilling" hole was to not drill, but instead to melt holes. Matt from the Planeteer team can be seen below in Figure 25 heating up the nail to puncture a hole through the globe.

Figure 27. Planeteer Matt Bauzon heating up a nail to melt holes in Plexiglas globes.

Description of How Prototype Differed From Planned Design:

The conceptual prototype built for the Gear It Up project was used as a proof-of-concept, to show that indeed a bicycle crank with an intermediate gearing step-up could drive a fan to levitate a ping-pong ball. While valuable lessons were taken from the building of the prototype, the final design differed greatly in structure and appearance from the prototype. The drive system was very similar, in that the bicycle crank when from a large chain-ring to the smallest, 14-tooth gear on a cluster, and from the largest, 28-tooth gear to a 14-tooth cog on the fan. While the prototype was all mounted on a single,

level piece of plywood, the final design brought the whole system up vertically into the third dimension. The cranks were at two separate heights, and the fans mounted below each on their own individual sheets of MDF particle wood. On top of that, the final design was completely encased in Plexiglas to prevent users from injuring themselves on the moving components of the bike-drive system.

Chapter 6: Exhibit Testing & Modifications

Due to the nature of the Gear It Up exhibit, there was little opportunity for external endurance limit testing of the individual components of the machine. All features of the exhibit that could be subject to breaking during use were laboriously manufactured with only the amount of materials necessary. For the purpose of creating a functioning exhibit that would not fail while in use at the Children's Museum, it was not desired to test the machine to its *limit*, but instead to test it under expected conditions and ensure that it would withstand the abuse of children playing with it. With these expectations, Gear It Up was tested by a means of *in use testing*, which is to say that it was used continuously for many hours, until all issues that arose were resolved and it was trusted that the machine would survive the Children's Museum.

The following sections detail issues that arose during testing, their solutions, and the CP Planeteers' conclusions for each problem:

Fan Vibrational Dampening:

When the frame, fans, and bicycle components were all mounted and in place, the action of the Gear It Up exhibit could be tested by cranking the pedals and watching the balls move in the tubes. Initial use of Gear It Up caused heavy vibrations in the fans, due to the repeated excitation of the user's input to the pedals. The inconsistency of human pedaling action caused a continuous vibrational input to the system, resulting in heavy fan vibrations which could potentially cause premature fatigue failure at the MDF wood that the fans were mounted upon, pulling the wood screws out and causing a structural failure of the machine.

Solution: Add dampening agents to the assembly of the fans.

Dampening agents were included between the fans and the MDF wood that they were mounted to, decreasing the effects of the fans' vibrations against the wood. It was decided that rubber washers would be the best materials to use for this component, and in the "reuse, recycle" spirit of the Gear It Up project, these were manufactured from scrap rubber bicycle tire tubes. Using scissors, the CP Planeteers cut 1" x 1" squares of rubber, with ¼" holes in the centers, and these were added between the fans and the MDF wood as washers on the bolts. Since the addition of these rubber washers, vibrations in the fan have been noticeably reduced.

Bicycle Chain Misalignment:

Initial testing of the lower crank set-up revealed misalignment of the bicycle chain between the chain-ring and the gear cluster. The chain-ring and the small cog to which it was chained were not in the same plane in space; while they were parallel, the cog was "outside" of the plane of the chain-ring by 0.5". For this, and due to existing wear of the smallest cog on the gear cluster, the chain was prone to slip off the cog and attempt to "shift" into the next largest gear. When this would happen the whole crank set-up would seize due to the chain being overstretched, and the crank would stop abruptly.

Solution: Chain alignment device.

In order to prevent the chain from shifting into the larger cog, an alignment device was added to cause the chain to move from the plane of the chain-ring into the plane of the small cog before connecting. This device was in the form of a make-shift roller-guide, which would push the chain over slightly but allow it to move past relatively freely. This was in the form of a 2" long, ¼"-20 bolt, complete with a 1" long nylon spacer that turned freely over the bolt, held in place with two nuts tightened against one another, and in turn bolted through the chain-stay of the bicycle frame at a convenient location.

This chain alignment device now prevents the chain from trying to shift into the larger cogs, and consequentially there have been no abrupt seizures of the crank set-up since its addition. As the nylon spacer can move freely, it acts as a bearing, and has caused no noticeable friction in the system.

Second Pedal Difficulties:

During testing of the prototype to Gear It Up, it was decided that a two-pedal crank system would be more desirable than a single-handed crank. The thought behind this was that with the second pedal, if a young child were unable to crank fast enough to cause the ball to lift, an accompanying parent or sibling could assist by cranking with the opposite pedal. During initial testing, most if not all volunteer users of the exhibit would resort to using just one hand to crank. It turned out to be simpler to crank with one hand than two, if only for the fact that you do not have to coordinate with two hands. When mounting the crank covers, it became apparent that it would be much easier to cover a crank with one crank-arm, on the opposite side of the chain-ring, than with two.

Solution: Remove second crank-arm and pedal.

Figure 28 Small chain-ring with crank arm cut off and ground down.

With all the evidence presenting itself, the second crank-arm and pedal were cut off, and the Gear It Up crank systems were converted to single-pedal set-ups. This removal also improved the overall safety of the exhibit, as the second pedal was a source of danger for children who approached the crank from the opposite side from where a user was already cranking.

Visual Indicator Additions:

After the visit by Jennifer Jipson and Kathy Chen, SLOCM board member, suggestions were received regarding visual indicators of the moving air within the tubes. In response, two additions were made:

1. **Ribbons within the tubes** – these brightly colored ribbons will move and flicker with only a small amount of air flow, providing the user with visual confirmation that the fan is working before the balls actually rise. This is especially important for younger visitors who will have difficulty causing the balls to rise at all, as they are encouraged to keep pedaling by the movement of the ribbons.
2. **Multiple ping-pong balls** – with three ping-pong balls in the tubes rather than one, the balls actually rise easier than they would alone. This is because the additional space blocked by the balls allowed less of the air to freely blow through the tube, but instead was forced to cause lift on the balls.

User Feed-back:

One of the most important criteria for Gear It Up to meet was entertainment value to children, and customer satisfaction. The CP Planeteers decided to base the entertainment value of Gear It Up on users overall reaction to the exhibit. From the moment that Gear It Up reached sufficient completion to be played with, it constantly attracted the attention of other engineering students working in the ME Hangar alongside the Planeteers. These volunteer users were consistently stoked by Gear It Up, and despite their hardest pedaling, the machine always stood up to their abuse.

Figure 29 Freshman ME student having a blast with Gear It Up!

Around the time of machine completion, Jennifer Jipson of the Cal Poly Child Development department visited the hangar with her 3-year old daughter, Bixby, to test out Gear It Up. Unfortunately Bixby was unable to pedal fast enough to cause the ball to rise, but this was not unexpected as she was considerably below the design age (8-10 years old). Another opportunity to test Gear It Up with children arose at the Senior Project Expo, where several children were present. All of the children who saw the exhibit were excited to crank it, and had a blast seeing the balls hover. Fortunately the SLO Chidren's Museum director and board members were present to witness the children in their enjoyment of the exhibit, and remarked that it was a "job well-done", and "complete success".

Chapter 7: Conclusions and Recommendations

Gear It Up has proven to be a strong success for the CP Planeteers and the San Luis Obispo Children's Museum. The exhibit captivates its audience, entertains children, and is fun for users of all ages. The learning objectives of the exhibit were well demonstrated when at the Expo a child of about 7 years of age claimed, "I know how it works!" and proceeded to explain to use the energy transfer from his pedaling of the crank to the intermediate gear cluster, to turning the fan and producing the air stream. When asked why one was easier to cause the ball to hover than the other, he explained that they must be geared differently, and related the project to his bicycle.

It was a pleasure to build an exhibit for the SLO Children's Museum, and to know that the result of all the hard work and dedication of the CP Planeteers will live on in the town of San Luis Obispo long after these students have graduated and moved on to other parts of the world. To see Gear It Up in action, visit the San Luis Obispo Children's Museum at 1010 Nipomo Street in Downtown San Luis Obispo. Adults are only admitted accompanying a child, so bring along your son, daughter, niece, nephew, or any young person in your life who you would like to share a fun learning experience with.
Future additions to Gear It Up could potentially include an electrically-powered portion. The fan impeller is still connected to the motor originally used to drive the fan, and by turning this motor with the crank system a voltage could potentially be generated. By harvesting this electric power, household appliances could be powered while simultaneously making the balls hover. Children would learn how much power is required by themselves to produce the electricity necessary to power the electric appliances that they are familiar with in their homes, and maybe even be inspired to conceive new means of obtaining the electricity we use in our society.

Appendix A: QFD

Human Powered Exhibit for the SLO Children's Museum		Weighting (Total 100)	Desired Fan RPM	Airstream Lift	Size	Budget	Leg length	ADA Sufficient	Weight	Mobility	Aesthetics	Reliability	Maintenance	Captivation	Educational	Kid Blower	Bicibomba Movil	Bike Blower
			Engineering Requirements													**Benchmarks**		
Customer Requirements	*Appealing, fun	12	1					1			9			9		3	1	3
	Inquiry based, hands-on	7												9	9	3	3	3
	Can do on repeat visits	4			1					1		1		3		1	0	3
	Multiple entry points	4					3	9						3		0	0	0
	*Interactive, collaborative	12						9			3	1		3	3	1	1	1
	Self-explanatory	5											3	3		3	1	9
	Experience hard to repeat somewhere else	3				1				3				3		0	3	1
	Fits SLO theme	3								1	9			3		0	0	0
	*Low maintenance	9										9	9			1	0	3
	Reasonable space and power requirements	3	9		9											1	9	9
	*Durable	13										9	9			1	3	6
	*Safe	13		3												0	0	9
	Sustainable	3														1	9	9
	Learning objectives (STEM)	5												3	9	0	0	0
	Attractive for field trips	2					3	3		1	9			9	3	3	1	3
	Portable	2			1				3	9			3			0	9	1
	Units		RPM	g	sq ft	$	inches		lbs	minutes		down days/year	minutes/day	minutes	Satisfies STEM			
	Targets		1550	50	30	1000	18-26	yes	50	10	yes	<10	2	5	yes			
	Kid Blower		9	9	9	9	1	0	9	0	1	1	3	1	0			
	Bicibomba Movil		3	0	9	9	0	0	9	9	1	1	3	0	0			
	Bike Blower		9	9	9	9	3	0	0	1	3	3	3	3	0			

9	Srong Correlation
3	Medium Correlation
1	Small Correlation
0	No Correlation

Figure 30 Quality Function Deployment: House of Quality

Appendix B: Final Drawings

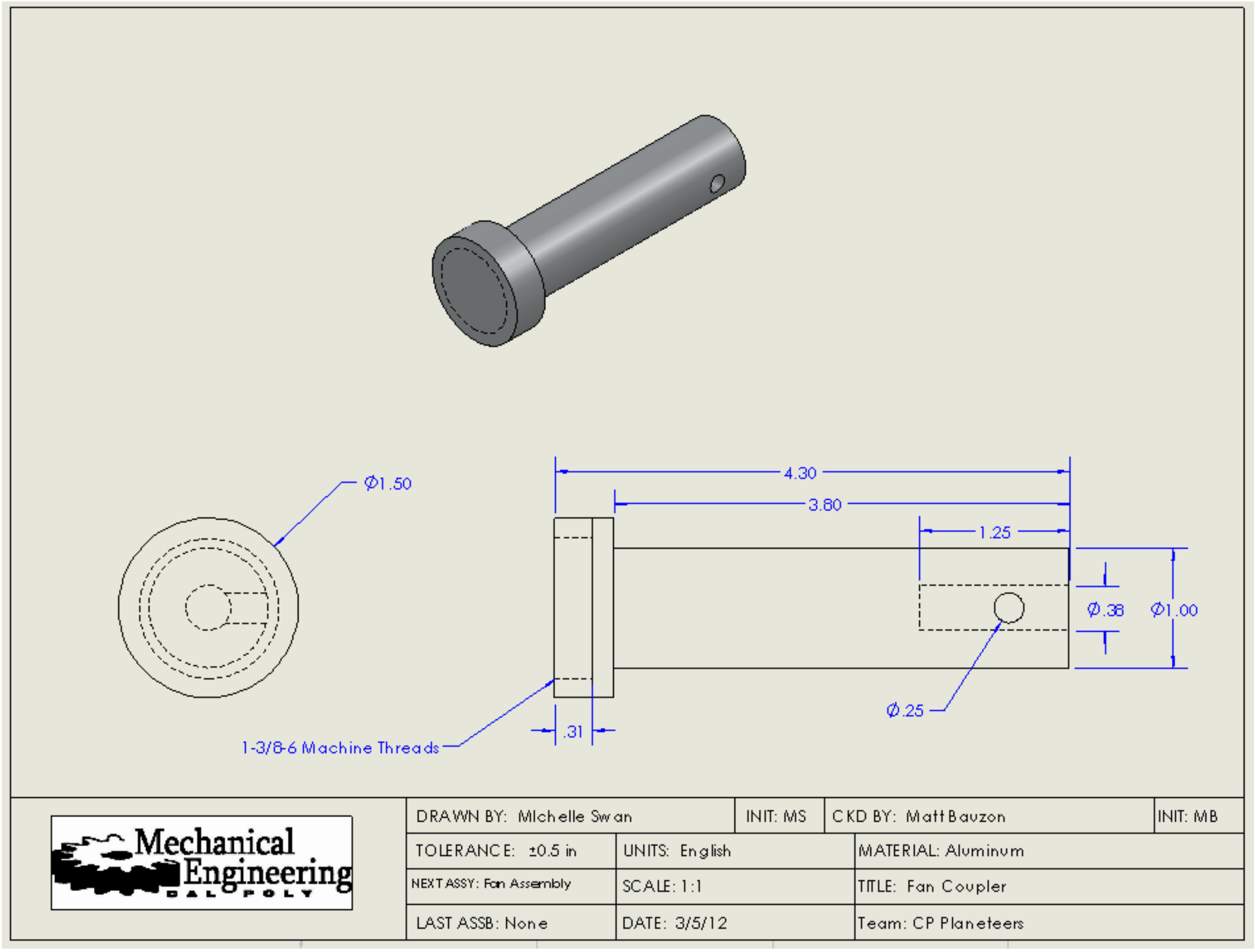
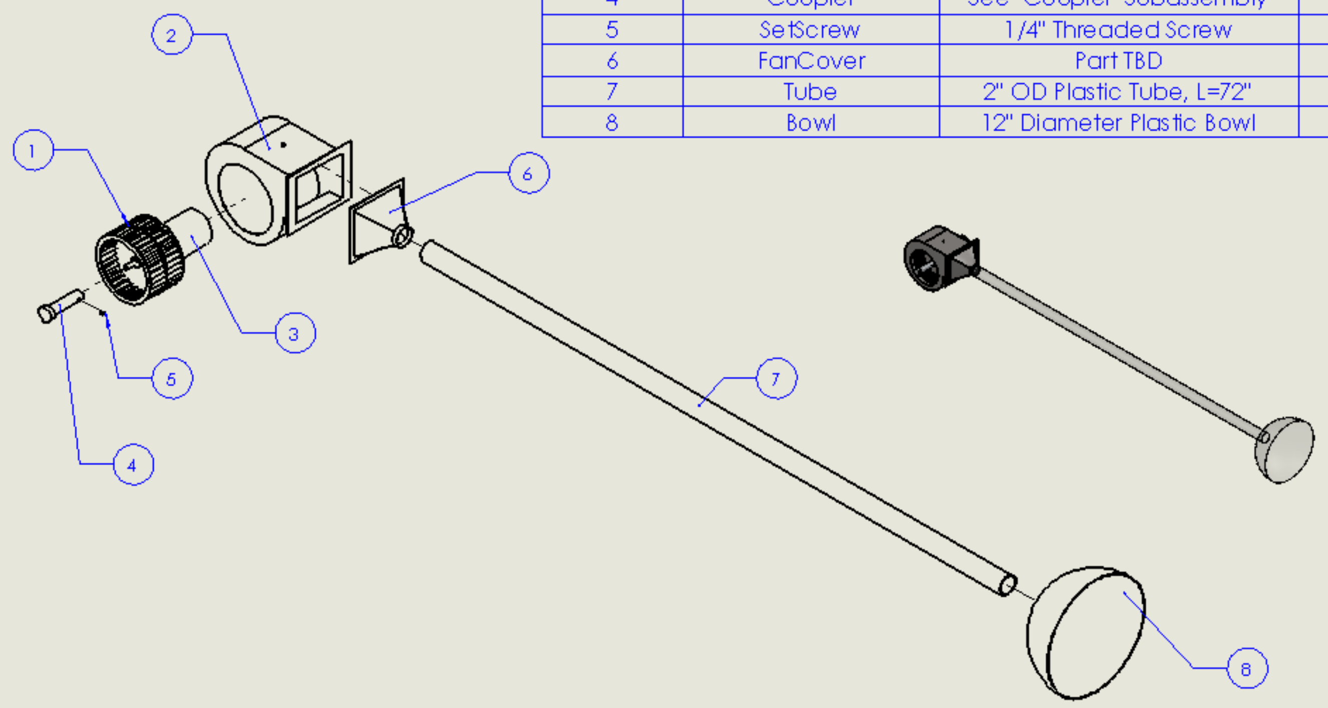


Figure 31 Coupler Detailed Drawing

ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	Zephyr Z8 S/H Fan	See Manufacturer's Info	1
2	Case for Z8 Fan	See Manufacturer's Info	1
3	Motor for Z8 Fan	See Manufacturer's Info	1
4	Coupler	See "Coupler" Subassembly	1
5	SetScrew	1/4" Threaded Screw	1
6	FanCover	Part TBD	1
7	Tube	2" OD Plastic Tube, L=72"	1
8	Bowl	12" Diameter Plastic Bowl	1

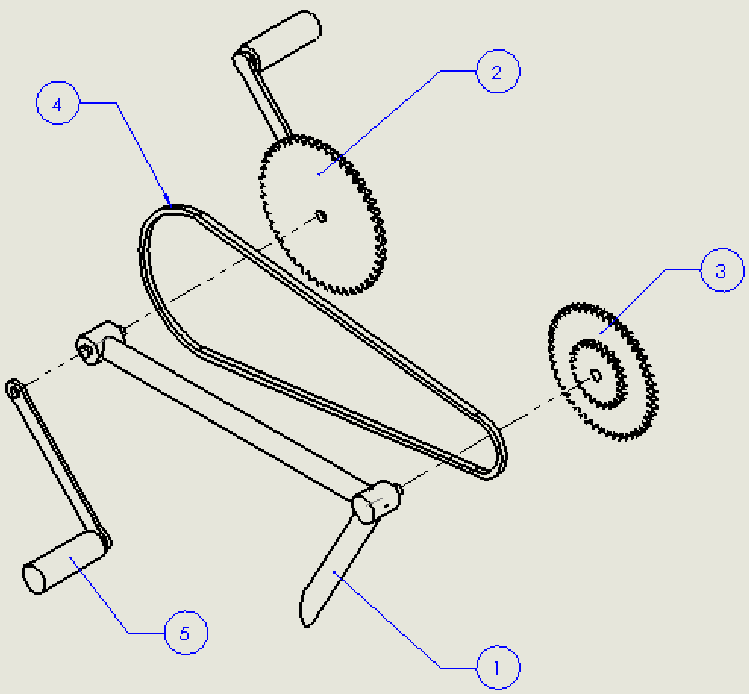


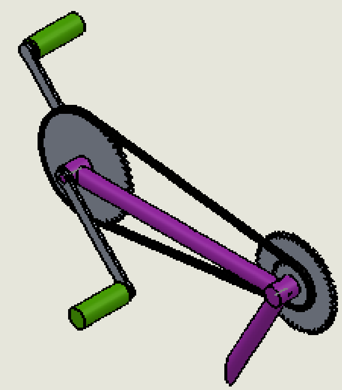
Mechanical Engineering CAL POLY

DRAWN BY: Michelle Swan	INIT: MS	CKD BY: Matt Bauzon	INIT: MB
TOLERANCE: ±0.5 in	UNITS: English	MATERIAL: Various	
NEXT ASSY: Final	SCALE: 1:12	TITLE: Fan Assembly	
LAST ASSB: Fan Coupler	DATE: 3/5/12	Team: CP Planeteers	

Figure 32 Fan Assembly

ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	Cut Bike Frame	Acquired from Bike Graveyard	1
2	Crank Set	Acquired from Bike Graveyard	1
3	Gear Cluster	Acquired from Bike Graveyard	1
4	Chain	Purchased	1
5	Pedal	See hand-drawn Pedal Assembly	2





DRAWN BY: Michelle Swan	INIT: MS	CKD BY: Matt Bauzon	INIT: MB
TOLERANCE: ±0.5 in	UNITS: English	MATERIAL: Aluminum, Steel, Rubber	
NEXT ASSY: Final	SCALE: 1:6	TITLE: Bike Assembly	
LAST ASSB: None	DATE: 3/5/12	Team: CP Planeteers	

Figure 33 Crank Arm Assembly

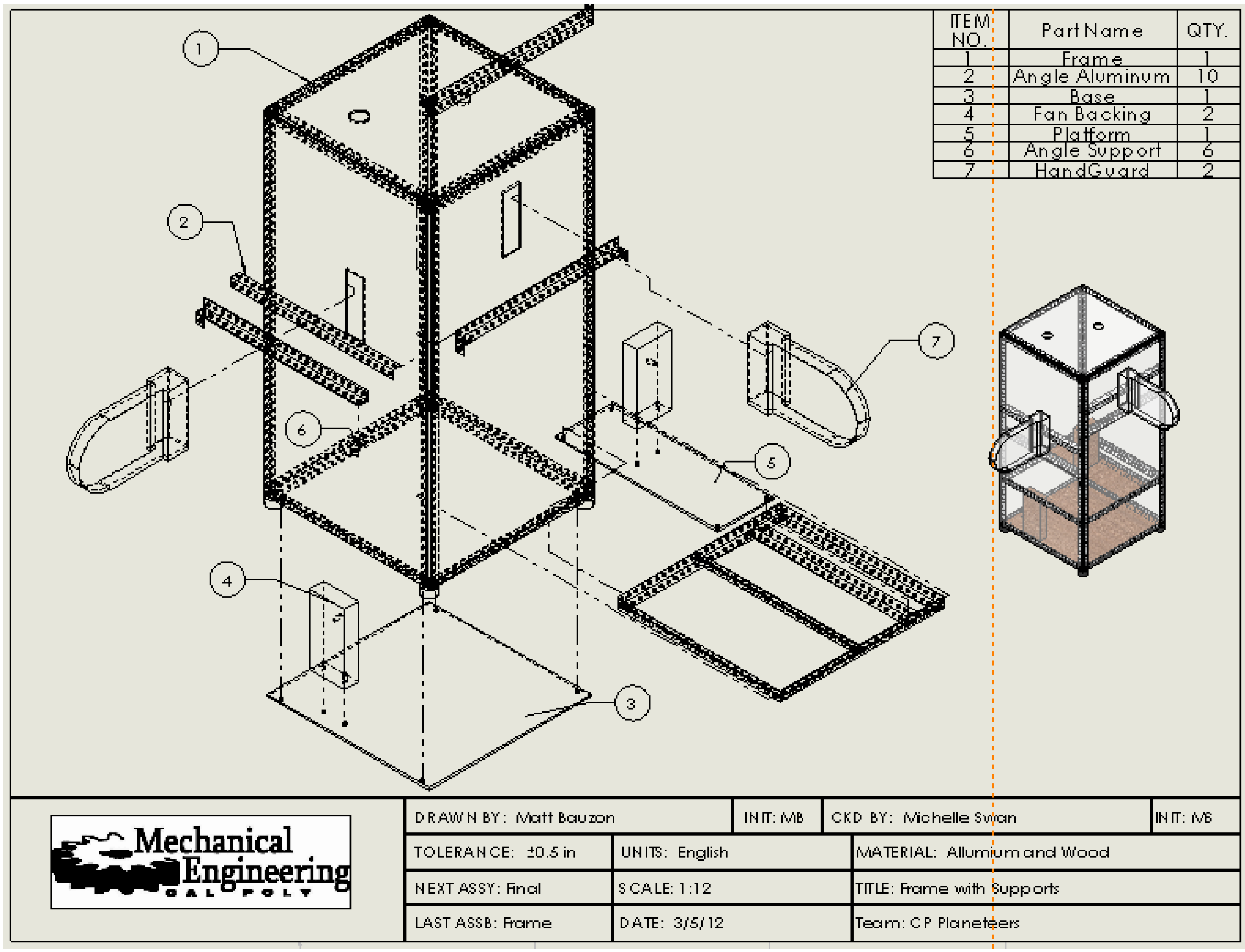
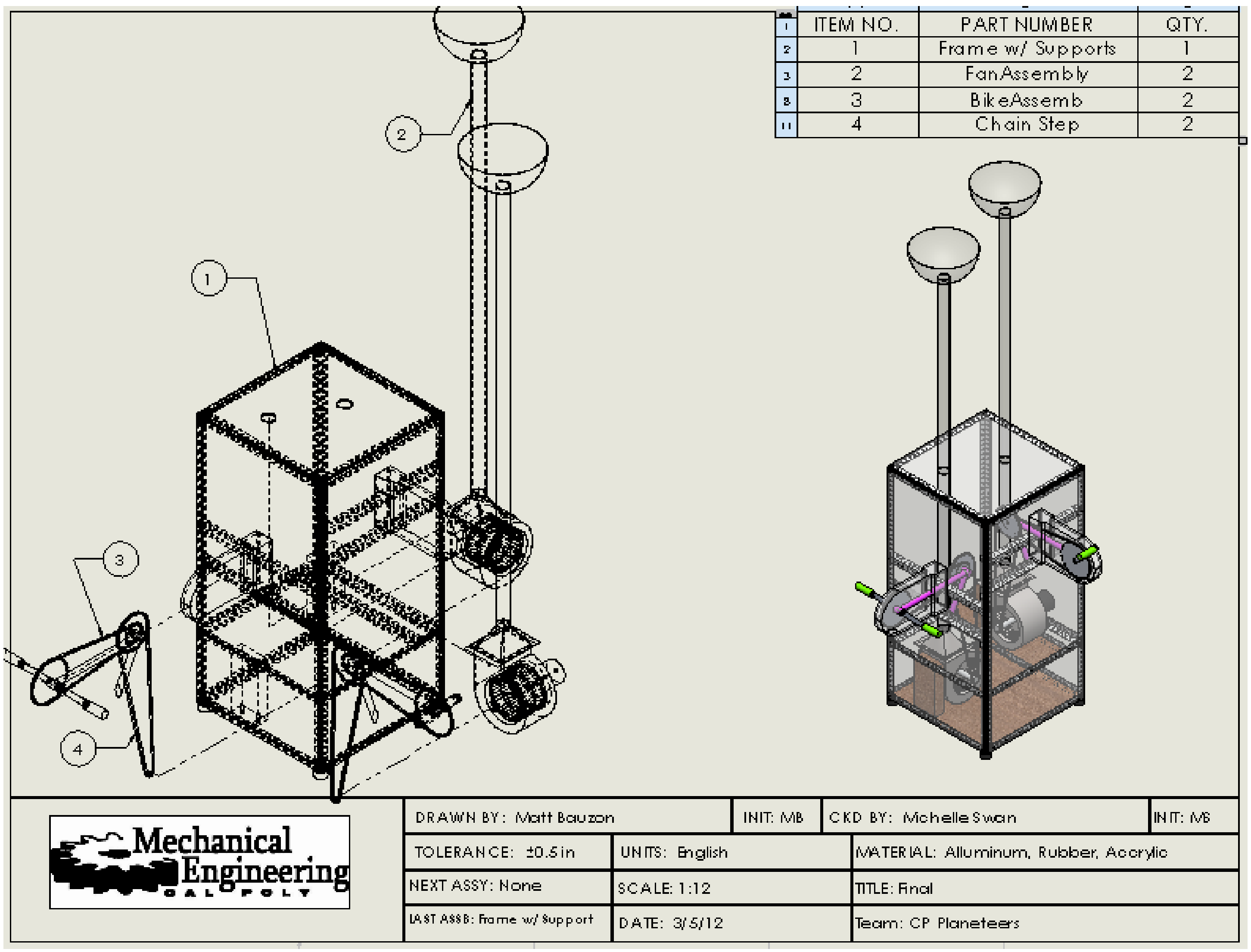


Figure 34 Frame Assembly



ITEM NO.	PART NUMBER	QTY.
1	Frame w/ Supports	1
2	FanAssembly	2
3	BikeAssemb	2
4	Chain Step	2

Figure 35 Final Assembly

Appendix C: Bill of Materials and List Of Venders

Table 2 Venders List, Contact Information and Pricing

	Planeteers' BOM for Gear it Up SLOCM Exhibit				Date of BOM:		6/3/2012
	Item	**Dimensions**	**Qty**	**Cost / item**	**Total cost**	**Amount Saved**	**Source**
1	Plexiglas tubes & sheets	96" x 48" sheet, 3" x 72" tubes	-	-	$272.94	$148.00	American Plastics
2	Blower (Zephyr z-8s/h)	6" diam x 4" wide impeller	2	$150.00	$150.00	$150.00	Penn-Barry (Randy 805-649-1225)
3	Galvanized angle steel	12GA x 1-1/4" x 8' with 3/8" Holes	7	$8.99	$96.50		Fastenal
4	bike chain	~234" narrow tooth	5	$11.66	$62.80		CBO
5	steel ball bearings	7/16" ID, 7/8" OD, 1/4" W	10	$4.65	$54.65		American Plastics
6	Paint, primer (Rustoleum)	White, Orange, Green, Blue	10	$4.99	$49.90		?
7	Soma bike cog	3/32" thick, 14teeth	2	$24.73	$49.46		CBO
8	Oury hand grips	Green, Orange	2	$9.99	$19.98		CBO
9	aluminum posts	1/4" x 2" long	20	$0.88	$17.60		ACE Hardware
10	aluminum shaft - cogs	1-1/2" diameter, 17" long	1	$10.00	$10.00		Precision Machining, Broad St.
34	Nyloc nuts package	1/4"-20	1	$7.71	$7.71		Fastenal
11	Loctite Threadlocker	red	1	$6.47	$6.47		Home Depot
13	long hex bolts	1/4"-20 x 1-1/2" long	32	$0.17	$5.44		Home Depot
14	RTV Silicon Sealant		1	$5.38	$5.38		McMastercarr/Hardware Store
15	short hex bolts	1/4"-20 x 3/4" long	38	$0.11	$4.18		Home Depot
16	ping pong balls	2.7 grams	6	$0.50	$3.00		Rite Aid
17	lower crank set	44 teeth	1	$3.00	$3.00		SLO Bike Kitchen
18	wood screws	8 x 1-1/2"	25	-	$1.94		Home Depot
19	carriage bolts	1-1/2" long	8	$0.18	$1.44		?
20	Vinyl tubing	clear	1	$1.17	$1.17		?
21	set screws	1/4"x3/8"	2	$0.46	$0.92		Home Depot
22	washers	1/4" ID	1	$0.2	$0.25		Fastenal

	package			5			
23	upper bike frame	42" height	1	-	$0.00	$50.00	bicycle graveyard...
24	lower bike frame	30" height	1	-	$0.00	$50.00	bicycle graveyard...
25	upper crank set	52 teeth	1	-	$0.00	$3.00	bicycle graveyard...
26	gear clusters	6-speed shimanos	2	-	$0.00	$10.00	bicycle graveyard...
27	pedal spindles	2.5"	2	-	$0.00	$3.00	bicycle graveyard...
12	aluminum shaft - pedals	1-1/8" diameter, 20" long	1	-	$0.00	$6.00	Precision Machining, Broad St.
28	MDF plasterboard	48" x 48" x 1/2"	1	--	$0.00	$10.00	Lee McFarland Donation
29	wodden base		1	--	$0.00	$40.00	Lee McFarland Donation
30	sheet metal - chain guard		1	-	$0.00	$12.00	Hayden's Metal
31	Sheet metal transitions	3.75"x5.75"x 6" tall	1	-	$0.00	$75.00	?
32	self-tapping screws	?	25	-	???		Home Depot
33	long self-tapping screws	?	6	-	???		Home Depot
			Total		**$824.73**		
			Total Saved:		$557.00		

Appendix D: Vendor supplied Component Specifications and Data Sheets

Dimensional Information & Performance Data

Zephyr

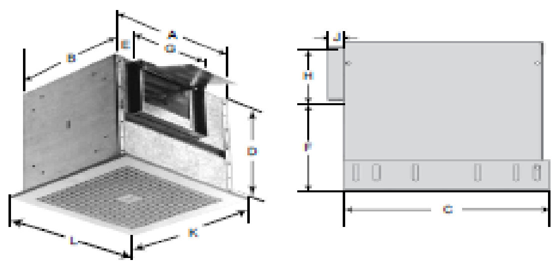
PENNBARRY

Z3 - Z12

Ceiling Exhaust Fans

› Zephyr Features & Dimensional Data

- Some Selections Below One Sone
- AMCA Air & Sound Certified
- UL Listed for UL705 and UL507
- All Motors with Thermal Overload Protection
- Quick Access Wiring
- Easy to Balance via Variable Speed Control (Lektrol)
- Field Convertible Discharge Orientation
- Field Convertible from Ceiling to Inline Installation
- Popular Models with Multi-Speed Motor (Wide Performance Range)



› Zephyr Dimensional References

Model	Housing							Outlet Duct			Grille	
	A	B	C	D	E	E[4]	F	G	H	J	K	L
Z3,5,6	12 1/2"	9 1/8"	16"	9 1/8"	1 1/4"	1 1/4"	5 3/8"	10"	3 1/4"	3/4"	11"	13 3/4"
Z8,81	13 7/8"	11 3/8"	17 3/8"	11 3/8"	1 7/8"	4"	5 1/4"	8"	6"	3/4"	13 1/4"	14 7/8"
Z10	18"	14 1/8"	21 1/2"	14 1/8"	3 5/8"	6 3/8"	8"	8"	6"	3/4"	15 1/2"	19 3/8"
Z12, 101, 102, 121	24"	14 1/8"	27 1/2"	14 1/8"	1"	1"	8"	22"	6"	3/4"	15 1/2"	25"

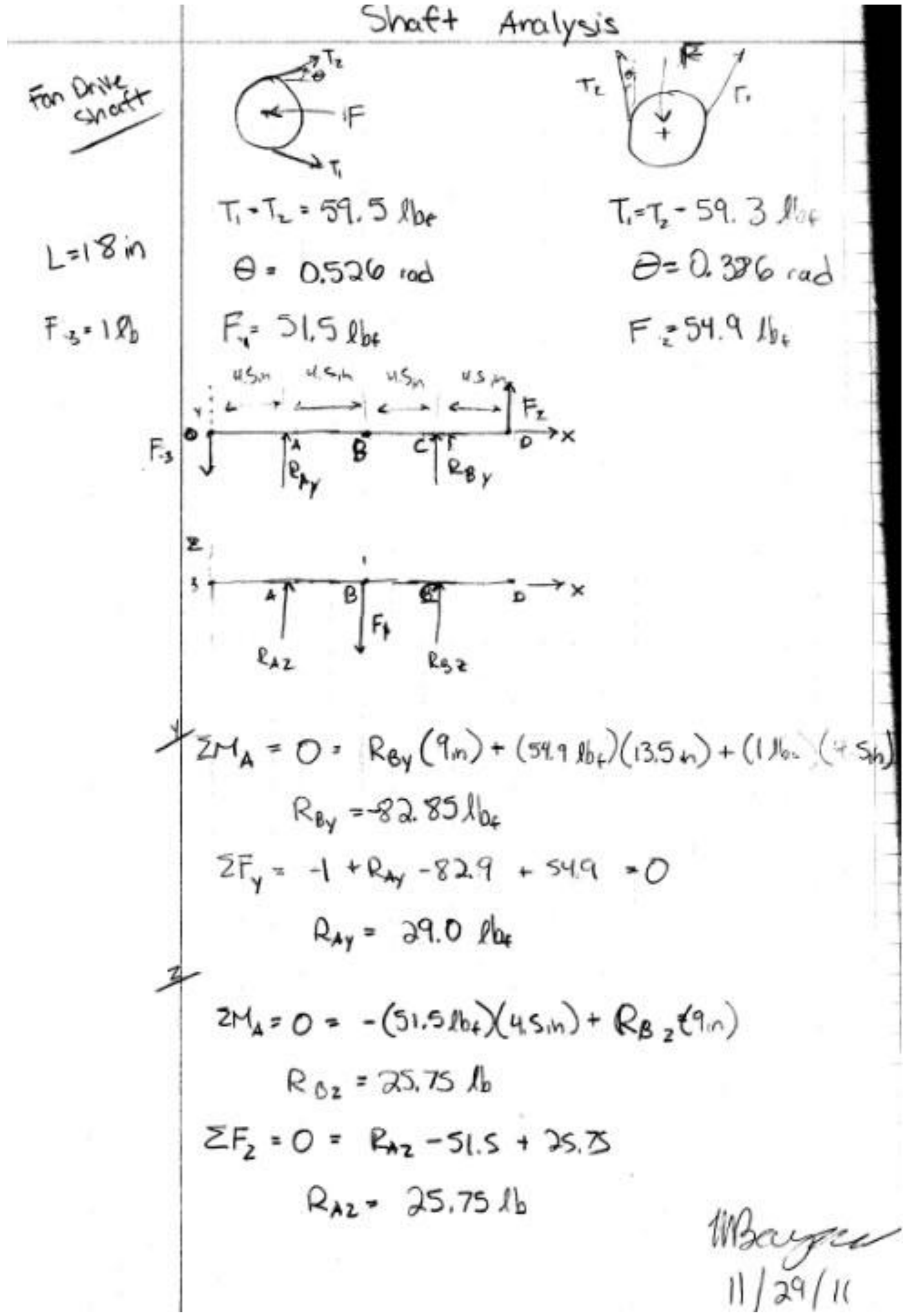
› Zephyr Performance Data

Model	MAX. WATT	Amps	RPM	SP	0.000"	0.125"	0.250"	0.375"	0.500"	0.625"	0.750"
Z3H	39	0.5	1550	CFM	109	83	-	-	-	-	-
				SONES[3]	1.7	2.3	-	-	-	-	-
Z5H	79	1	1550	CFM	192	163	128	93	-	-	-
				SONES[3]	3.4	3.3	3.3	3.4	-	-	-
Z6S[5]	47	0.6	1050	CFM	123	101	82	-	-	-	-
				SONES[3]	0.9	1.4	1.8	-	-	-	-
Z6H[5]	108	1.4	1550	CFM	230	196	166	122	-	-	-
				SONES[3]	3.3	3	3	3.1	-	-	-
Z8S[6]	77	1	1050	CFM	272	247	231	217	199	-	-
				SONES[3]	2.1	2.4	2.9	3.3	3.8	-	-
Z81S	77	0.9	1050	CFM	310	273	239	213	182	136	73
				SONES[3]	2.5	2.7	2.9	3.3	3.7	4.2	4.3
Z8H[6]	130	1.6	1550	CFM	426	401	377	357	341	328	304
				SONES[3]	4.5	4.7	4.7	5.1	5.6	5.8	5.8
Z10S[7]	243	2.5	1050	CFM	469	441	423	403	387	367	347
				SONES[3]	4.5	4.8	5.1	5.4	5.6	5.8	6
Z101S	153	1.6	1050	CFM	612	537	467	405	222	116	-
				SONES[3]	3.9	3.6	3.9	4.6	5.5	6	-
Z10H[7]	390	3.6	1550	CFM	728	694	664	638	613	591	565
				SONES[3]	8.6	8.6	8.6	8.7	8.6	8.8	8.8
Z102S	269	4.5	1050	CFM	816	747	691	602	335	-	-
				SONES[3]	5.8	5.8	5.4	5	4.9	-	-
Z12S	260	2.9	1050	CFM	901	855	812	755	683	552	-
				SONES[3]	5.8	5.9	6.3	6.5	6.5	6	-
Z121S	370	3.6	1050	CFM	1083	1062	1024	949	838	686	270
				SONES[3]	7	6.9	6.6	6.1	5.7	5.3	4.6
Z102H	812 (BHP 0.53)	7.5	1550	CFM	1435	1385	1338	1294	1247	1203	1163
				SONES[3]	11.8	11.7	11.9	11.9	11.7	11.3	11
Z12H	851 (BHP 0.65)	7.9	1550	CFM	1566	1511	1464	1417	1364	1307	1251
				SONES[3]	13.5	13.3	12.9	12.7	12.3	12	11.7

1. Speed (RPM) shown is nominal. Performance is based on actual speed of test. 2. Performance shown is for installation type B - Free Inlet, Ducted Outlet. Performance ratings include the effects of an inlet grille and backdraft damper in the airstream. 3. The sound ratings shown are loudness values in fan sones at 5ft. (1.5m) in a hemispherical free field calculated per AMCA Standard 301. 4. Specify discharge configuration. Standard types are RA, TD, TDA and TDA-RA. 5. Z6S and Z6H is the same unit shipped with EASYTAP dual speed motor. Wired on S (low) speed. 6. Z8S and Z8H is the same unit shipped with EASYTAP dual speed motor. Wired on S (low) speed. 7. Z10S and Z10H is the same unit shipped with EASYTAP dual speed motor. Wired on S (low) speed.

Zephyr

Appendix E: Analysis



Shaft Analysis

Fan Drive shaft

$T_1 - T_2 = 59.5$ lbf

$\theta = 0.526$ rad

$F_1 = 51.5$ lbf

$T_1 = T_2 - 59.3$ lbf

$\theta = 0.386$ rad

$F_2 = 54.9$ lbf

$L = 18$ in

$F_3 = 1$ lb

y: $\Sigma M_A = 0 = R_{By}(9\text{in}) + (54.9\ \text{lb}_f)(13.5\ \text{in}) + (1\ \text{lb}_f)(4.5\ \text{in})$

$R_{By} = -82.85\ \text{lb}_f$

$\Sigma F_y = -1 + R_{Ay} - 82.9 + 54.9 = 0$

$R_{Ay} = 29.0\ \text{lb}_f$

z: $\Sigma M_A = 0 = -(51.5\ \text{lb}_f)(4.5\ \text{in}) + R_{Bz}(9\ \text{in})$

$R_{Bz} = 25.75$ lb

$\Sigma F_z = 0 = R_{Az} - 51.5 + 25.75$

$R_{Az} = 25.75$ lb

M Bayer
11/29/11

Figure 36 Shaft Analysis

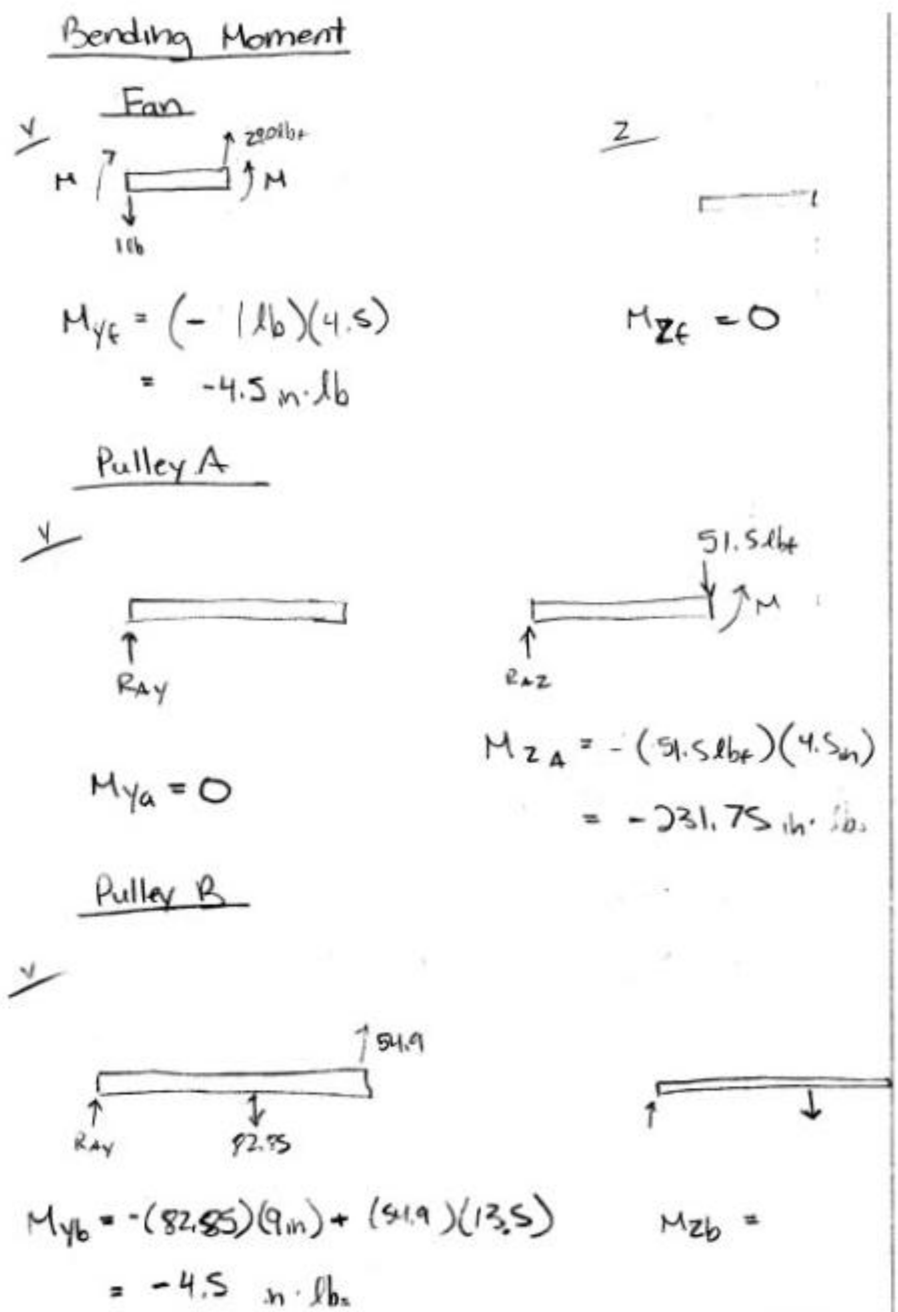
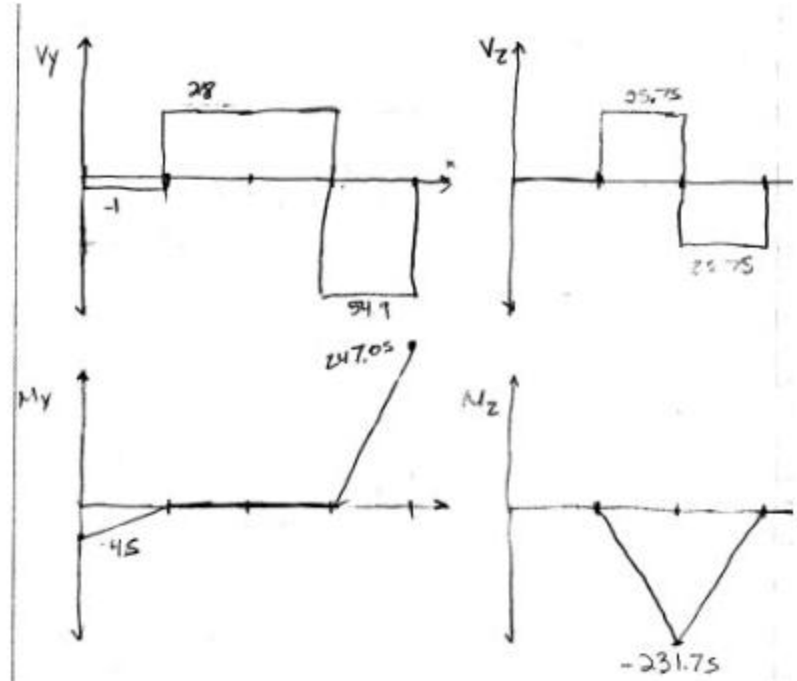


Figure 37 Shaft Analysis (cont.)



using factor of safety of 2

Goodman fatigue:

$$d = \left[\frac{16 n_f}{\pi} \left\{ \frac{1}{S_e}\left[4(K_f M_a)^2 + 3(K_{fs} T_a)^2\right]^{1/2} + \frac{1}{S_{ut}}\left[4(K_f M_m)^2 + 3(K_{fs} T_m)^2\right]^{1/2} \right\} \right]^{1/3}$$

$n_f = 2$

Aluminum, $S_{ut} = 35\text{ksi}$ $S_e' = 17.5\text{ksi}$

$S_e = K_a K_b K_c K_d K_e S_e'$

11/29/11

Figure 38 Shaft Analysis (cont.)

$$K_a = a S_{ut}^{b} = (2.70)(35)^{-0.265}$$

$$= 1.05$$

$K_c = 1$ $\qquad$ $K_e = 0.814$ [99% reliability]

$K_d = 1$

$$S_e = (1.05)(0.814)(17.5\ ksi) = 14.96\ Ksi$$

M_a is alternating

T is constant

$M_a = 247.05\ in \cdot lb$ $\qquad$ $T = 3.685\ in \cdot lb$

$$d = \left[\frac{16n}{\pi} \left\{ \frac{1}{S_e} \left[4 (K_f M_a)^2 \right]^{1/2} + \frac{1}{S_u} \left[3 (K_{fs} T_m)^2 \right]^{1/2} \right\} \right]^{1/3}$$

$K_f = 1$ $\qquad$ $K_{fs} = 1$

$$d = \left[\frac{32}{\pi} \left\{ \frac{1}{14.96} \left[4 (247.05)^2 \right]^{1/2} + \frac{1}{17.5} \left[3 (3.685)^2 \right]^{1/2} \right\} \right]^{1/3}$$

$$= \left[\frac{32}{\pi} \left\{ .0033 + .000363 \right\} \right]^{1/3}$$

$$d = 0.55\ in = 9/16\ in$$

Figure 39 Shaft Analysis (cont.)

Appendix F: Project Gantt Chart

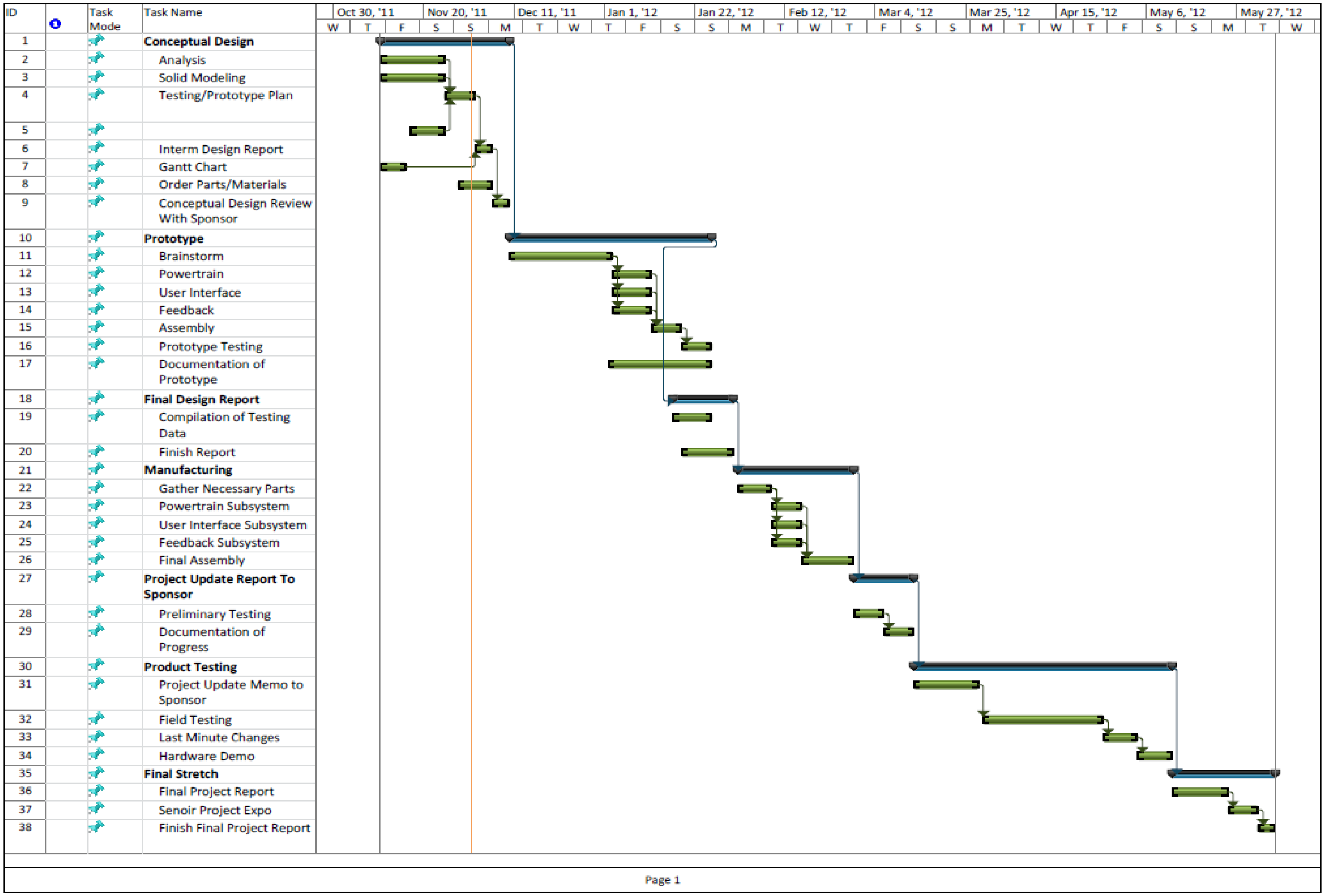


Figure 40 Gantt Chart depicting The Planeteers' schedule to finish Gear It Up by the Senior Project Expo in late May, 2012.

Appendix G: Ideation Progression

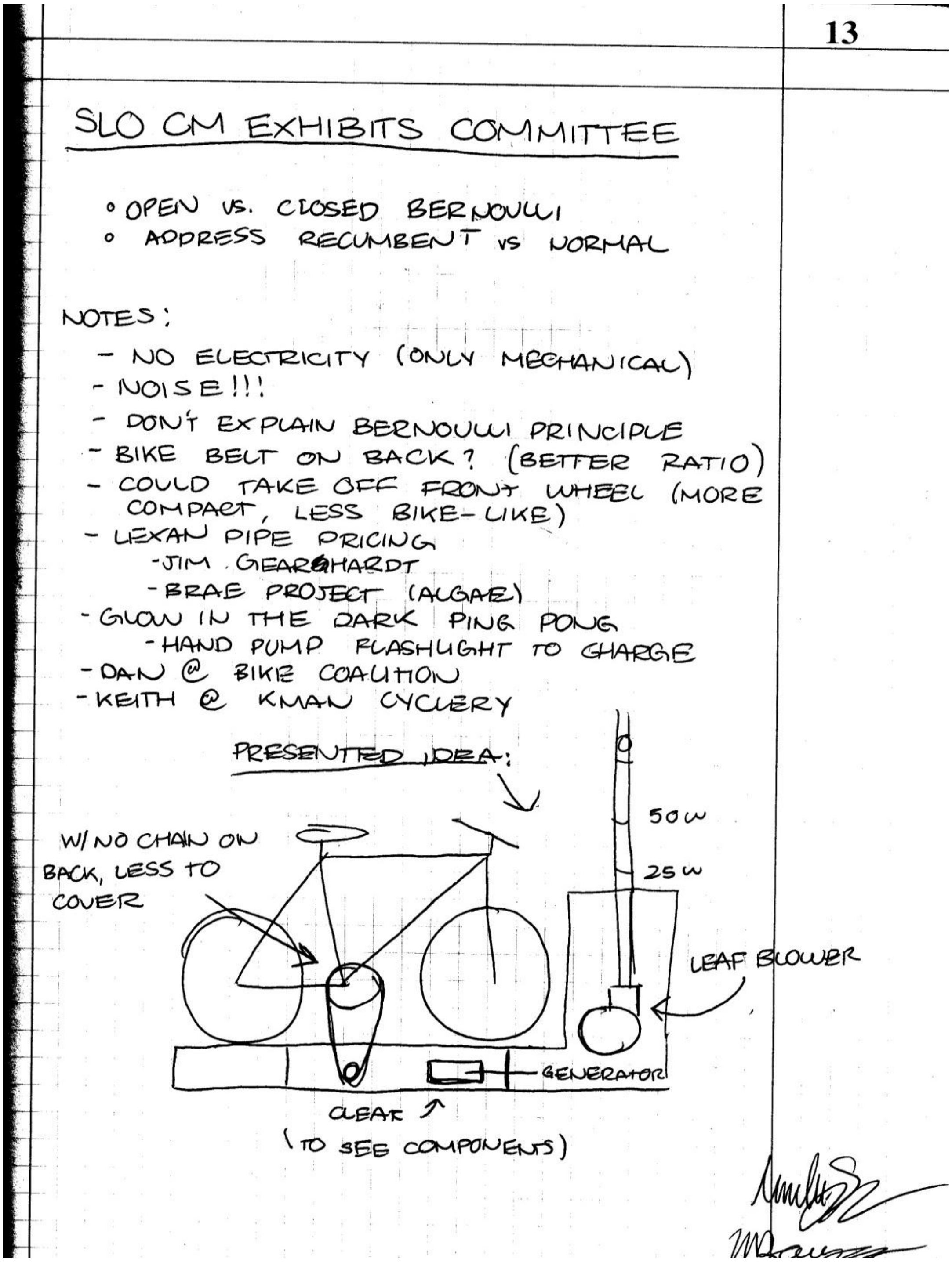


Figure 41 Feedback from Exhibits Committee

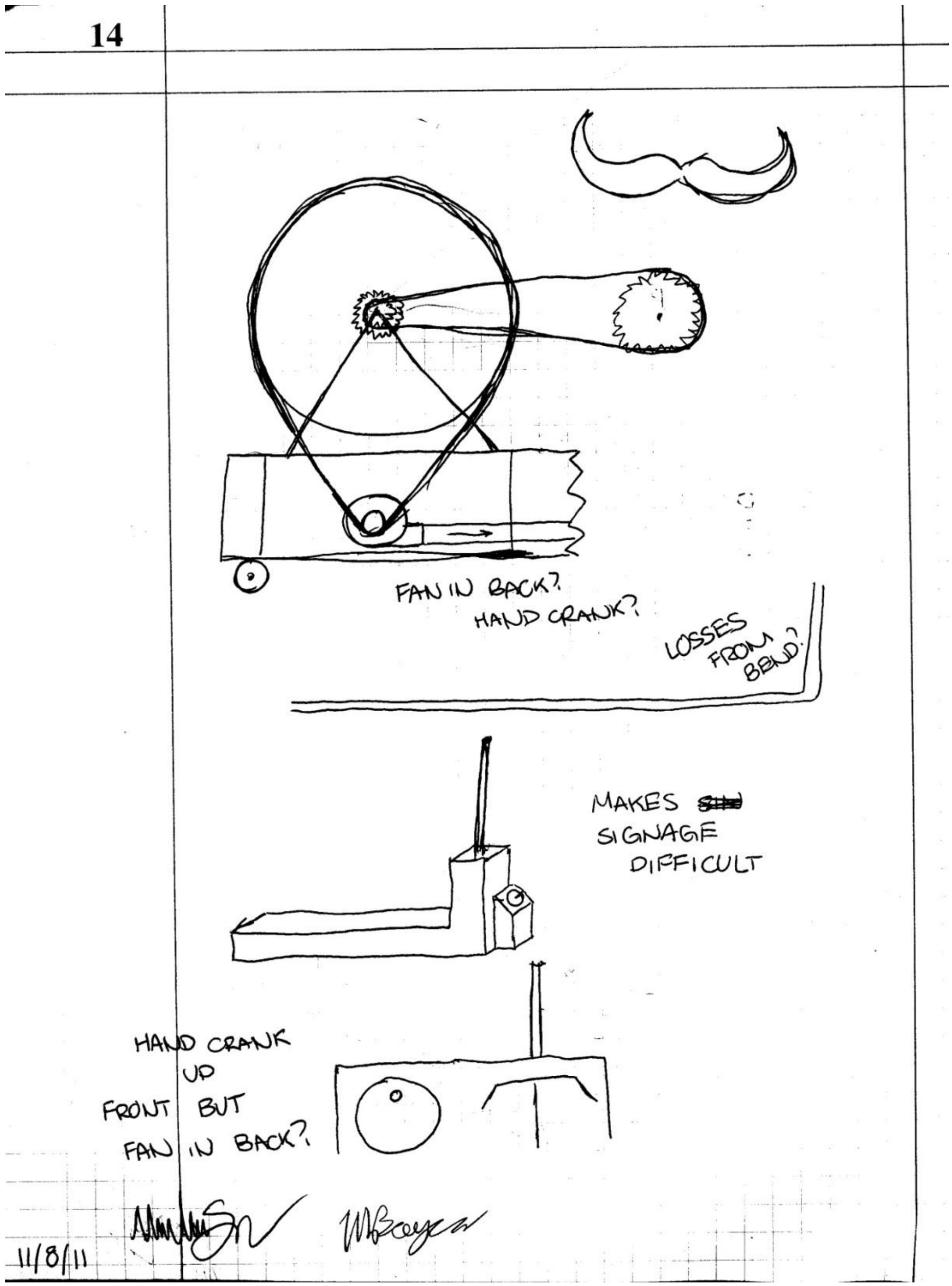


Figure 42 Fan-Below Platform Configuration for the Bike-Blower. While the Bike-Blower concept was scrapped for the updated Gear It Up design, drawings of these preliminary ideas show the idea progression of The Planeteers in their search for an optimum design.

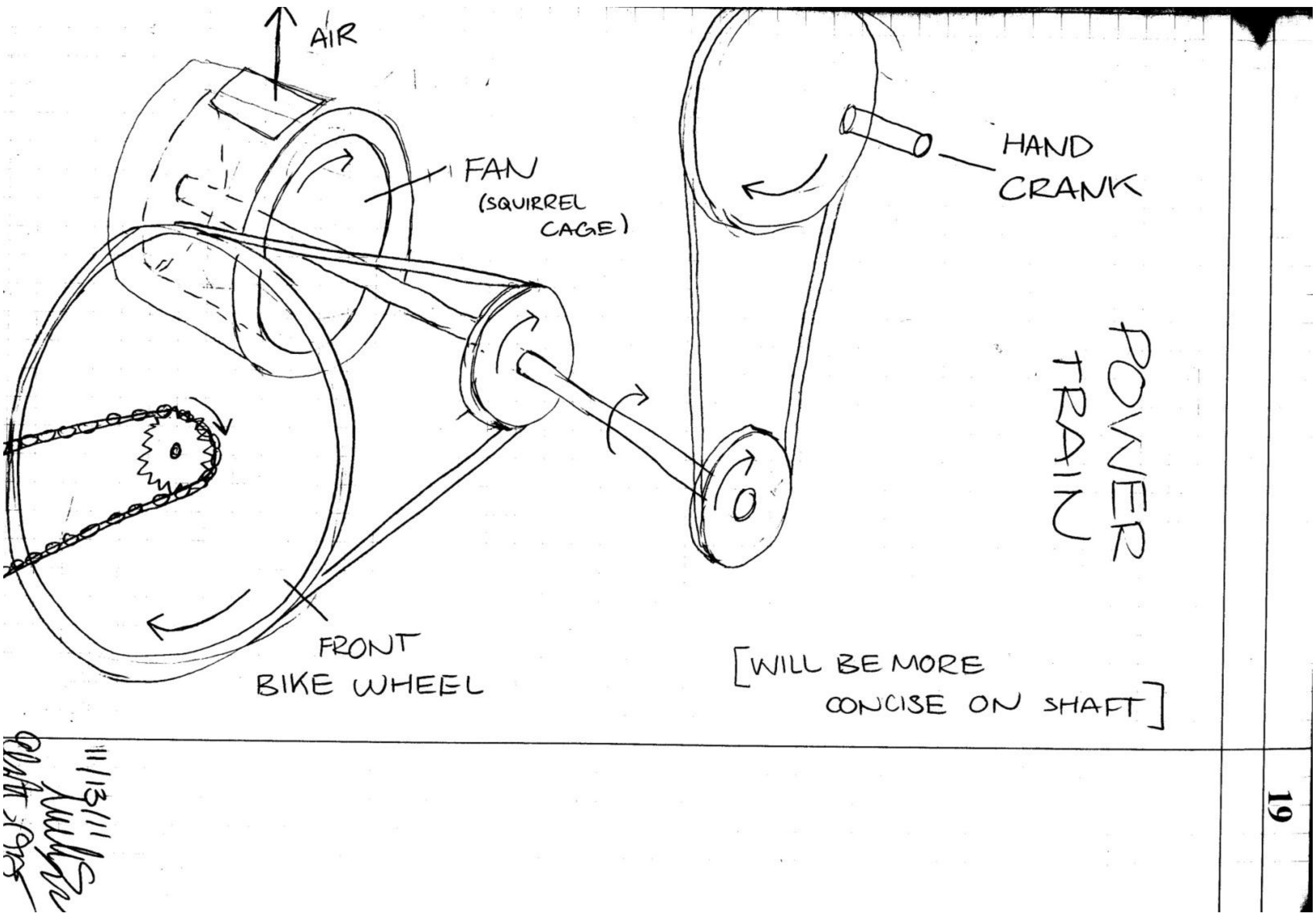


Figure 43 Bike-Blower Front Wheel Drive Configuration. While the Blower Bike idea was dropped along the way to the final Gear It Up design, the hand crank connection seen here is essentially what is being used in Gear It Up, except with a chain and gears instead

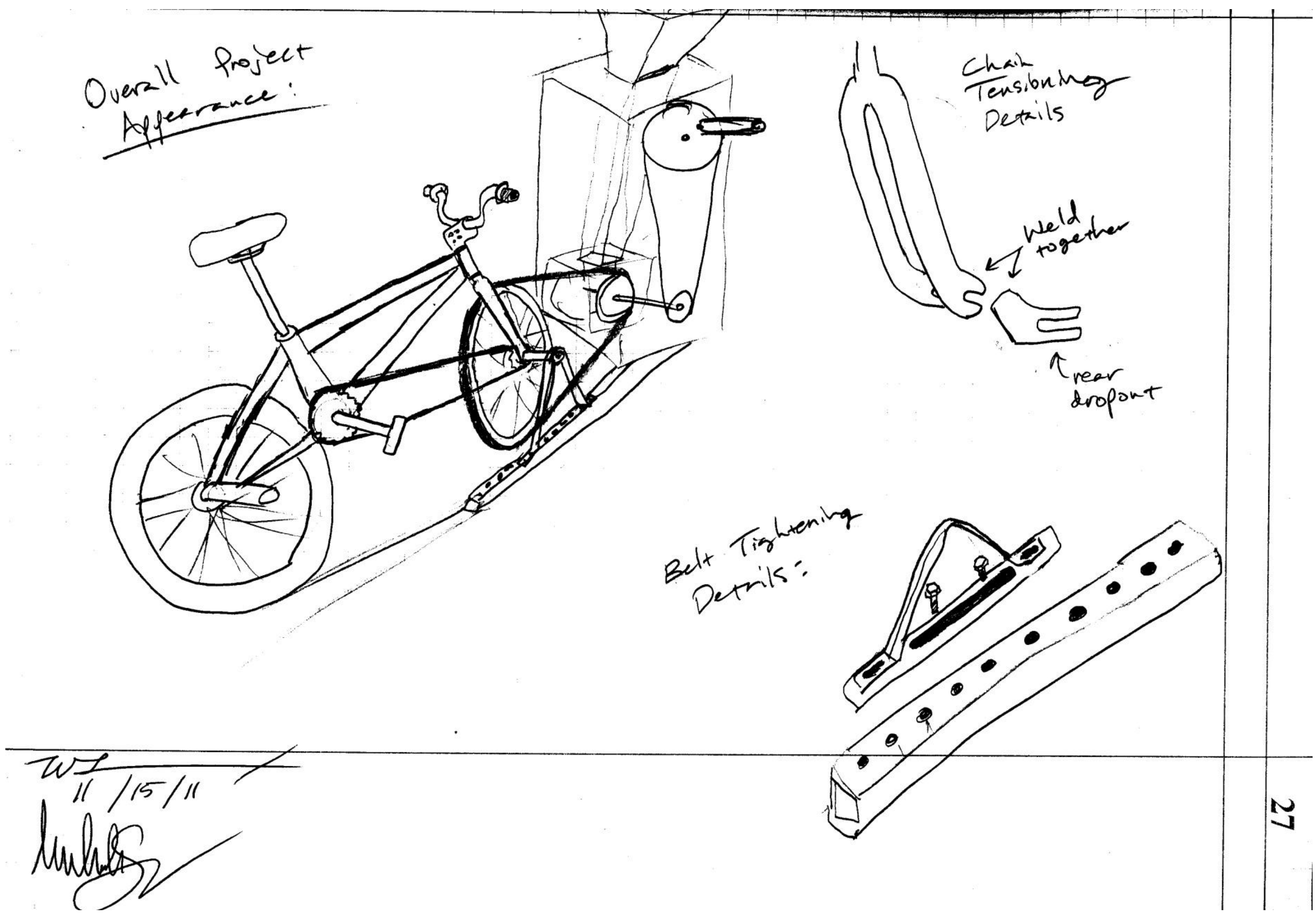


Figure 44 Bike Strut Construction

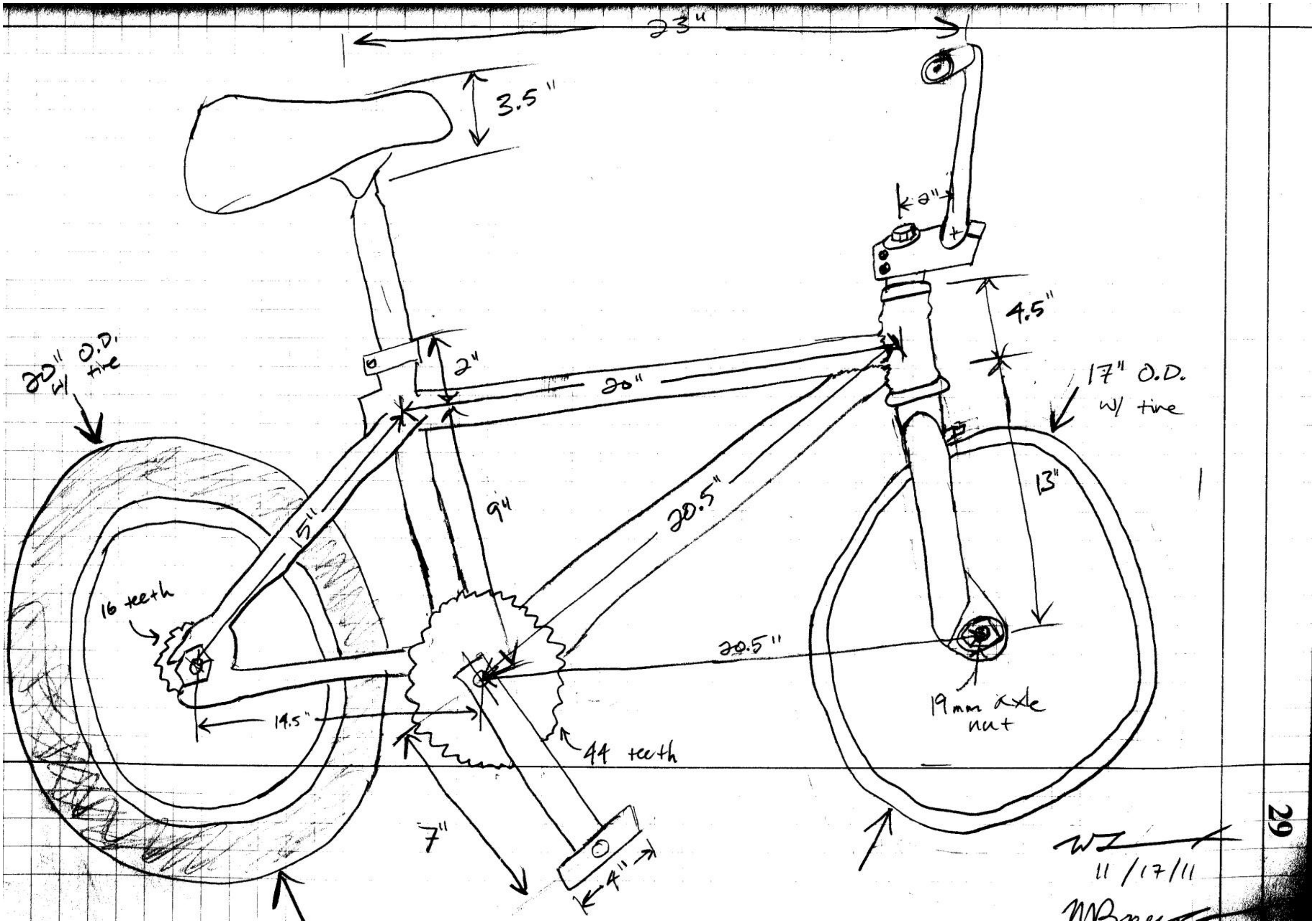


Figure 45 BMX Bike Dimensions